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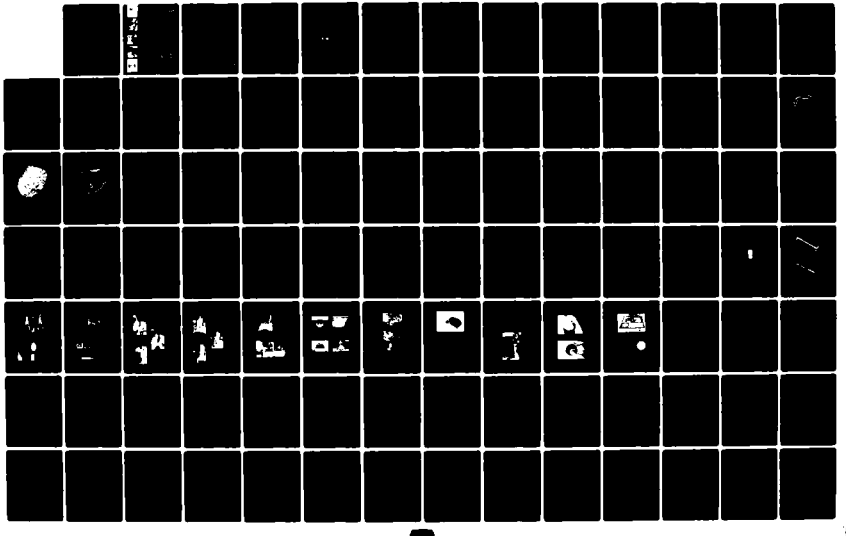

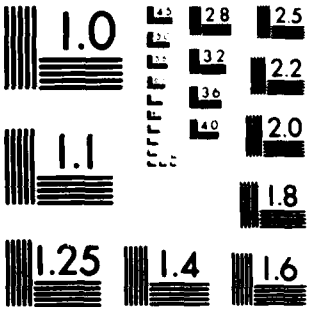

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ENVIRONMENTAL IMPACT RESEARCH PROGRAM

INSTRUCTION REPORT EL-83-2

12

AN INSTRUCTION REPORT ON FRESHWATER MUSSELS

by

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U. S. Army Engineer Waterways Experiment Station
P. O. Box 631, Vicksburg, Miss. 39180

September 1983

Final Report

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This Instruction Report contains information for Federal biologists and others on freshwater mussels. The content of this volume will aid in performing impact assessments and endangered species surveys where freshwater mollusks are involved. Information is provided on the following topics: collecting, preserving, and identifying mussels; methods for relocating and creating habitat for mussels; the commercial shell industry; and the technical literature concerning mussels.

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PREFACE

This document contains some of the results of a two-year study on freshwater mussels conducted at the U. S. Army Engineer Waterways Experiment Station (WES), Vicksburg, Miss. This work is part of the Environmental Impact Research Program (EIRP) and was sponsored by the Office, Chief of Engineers, U. S. Army.

This volume was written by Dr. Andrew C. Miller and Mr. David A. Nelson, WES. Specific information and technical assistance were provided by Ms. Linda Winfield and Mr. Randall Williams, WES; Dr. Robert H. King, Central Michigan University, Mt. Pleasant, Mich.; Dr. Arthur H. Clarke, ECOSEARCH, Inc., Mattapoisett, Mass.; Mr. Thomas M. Freitag, U. S. Army Engineer District, Detroit; Ms. Vechere' V. Lampley and Mr. Jim Scharber, U. S. Army Engineer District, Nashville; Mr. John Jenkinson, Tennessee Valley Authority (TVA); Mr. Bill Isom, TVA; Mr. Robert Whiting, U. S. Army Engineer District, St. Paul; Mr. James L. Peach, American Shell Company; and Mr. Rick Julian, Fish and Wildlife Service, East Lansing, Mich.

The authors would also like to acknowledge many other individuals, too numerous to mention, who participated in discussions and provided information at two workshops on freshwater mollusks, one at WES (April 1981) the other in St. Louis, Mo., (October 1982).

This study was conducted under the general supervision of Dr. Tom D. Wright, Chief, Aquatic Habitat Group (AHG), and Mr. Bob O. Benn, Chief, Environmental Systems Division (ESD). The ESD and AHG are part of the Environmental Laboratory of which Dr. John Harrison is Chief. Program Manager at WES for the EIRP is Dr. Roger Saucier; Technical Monitor at the Office, Chief of Engineers, is Mr. John Bushman.

Commanders and Directors of WES during the conduct of this study and the preparation of this report were COL Nelson C. Conover, CE, and COL Tilford C. Creel, CE. Technical Director was Mr. F. R. Brown.

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CONTENTS

CONVERSION FACTORS, INCH-POUND TO METRIC (SI) UNITS OF MEASUREMENT

Inch-pound units of measurement used in this volume can be converted to metric (SI) units as follows:

Multiply	By	To Obtain
acres	4046.873	square metres
cubic feet per second (cfs)	0.02832	cubic metres per second
Fahrenheit degrees	5/9	Celsius degrees or Kelvins*
feet	0.3048	metres
feet per second	0.3048	metres per second
inches	2.54	centimetres
knots	0.51444	metres per second
miles per hour (mph) (international)	0.44704	metres per second
pounds	0.45359237	kilograms

* To obtain Celsius (C) temperature readings from Fahrenheit (F) readings, use the following formula: $C = (5/9)(F - 32)$. To obtain Kelvin (K) readings, use: $K = (5/9)(F - 32) + 273.15$.

AN INSTRUCTION REPORT ON FRESHWATER MUSSELS

PART I: INTRODUCTION

Background

1. The freshwater mussels are an important economic, ecological, and cultural resource. Shells of certain species are used to make jewelry and form nuclei for cultured pearls. Many taxa are preyed upon and provide food for various species of fish, birds, and mammals. Because these organisms have specific requirements for clean, well-oxygenated water, they are often used as indicators or monitors of water quality conditions in lakes and rivers. Since they filter large volumes of water during feeding, they have the ability to concentrate undetectable contaminants. Their large size and potential for long life can make them the dominant invertebrates living on and in the bottoms of lakes or streams. Because of their wide distribution, members of this group of organisms are likely to be affected by many construction and maintenance activities conducted on waterways by the U. S. Army Corps of Engineers. In addition, there are now 25 species of mussels listed as endangered by the U. S. Department of Interior (see Federal Register, 11 April 1980) which must be considered under the Endangered Species Act by the Corps.

Purpose and Scope

2. This report was designed for use by biologists, planners, and individuals throughout the United States interested in environmental problems who may or may not have had extensive experience with freshwater mussels. Information contained herein will be useful for those preparing Environmental Impact Statements, Environmental Assessments, or conducting endangered species surveys. Some of the material is very general and of an introductory nature; other portions concern very specialized aspects of collecting, identifying, or preserving mussels. It is the intent of this document to deal specifically with the needs of the Federal biologist or planner who must make decisions about proposed

project impacts or assist in the design of new projects which could affect the habitat of freshwater mussels.

3. Part II of this document presents general information on the biology and natural history of freshwater mussels. Included is a glossary of terms and figures which depict internal and external features of these organisms. Because the biology of mussels is unique, many of the problems associated with sampling and protecting this group will be better understood after general background information on these invertebrates is obtained.

4. In Part III is a discussion of the techniques for constructing and methods for using various types of equipment to collect mussels. The efficiency of these gear types is presented in Part IV, and a discussion of how to design a sampling program for mussels is presented in Part V. The availability of information from the commerical shellfisherman concerning the local distribution of certain species is presented in Part VI.

5. Techniques for cleaning and preserving shells and soft parts of mussels appear in Part VII. Hints on identifying mussels, plus a taxonomic key to common species, are found in Part VIII. Included in this part is a list of contractors who can collect and identify mussels and a list of museums with reference collections of these organisms.

6. Part IX discusses methods for keeping freshwater mussels alive outside their natural habitats. Methods for sending mussels through the mail and maintaining them in aquaria are also presented in this part. Part X presents case histories of large-scale studies which have been recently conducted on relocating mussels from one area to another. Part XI discusses alternatives to relocating mussels; i.e., techniques for protecting or maintaining these invertebrates in their natural habitat. Habitat creation for mussels is the subject of Part XII; this part is based on the results of a study for the U. S. Army Engineer District, Mobile, concerning the design of a gravel bar habitat for mussels in the Tombigbee River.

7. Part XIII contains a brief synopsis of the salient technical literature on this group of organisms. This part will aid the reader in

choosing among the many scientific publications and articles that deal with freshwater mussels. A more exhaustive compilation of material on freshwater mussels entitled "An Annotated Bibliography of Freshwater Mollusks of the United States" is available from Dr. Andrew Miller at the U. S. Army Engineer Waterways Experiment Station, Vicksburg, Miss.

PART II: A BRIEF DISCUSSION OF THE BIOLOGY AND NATURAL HISTORY OF FRESHWATER MUSSELS

Introduction

8. Before attempting to collect and identify freshwater mussels, it is important to understand some of the unique aspects of molluscan biology. The manner in which these animals move, reproduce, feed, and respond to external stimuli deserves specific attention since these life functions are frequently affected by alterations to their habitat. The following general information on the biology of freshwater mussels has been summarized mainly from Parmalee (1967), Murray and Leonard (1962), and Fuller (1974).

Classification

9. Freshwater mussels are in the phylum Mollusca which is characterized by soft-bodied animals, most of which have a calcium carbonate shell secreted by a mantle. The class Pelecypoda contains bivalved mollusks which include oysters, marine clams, and the Asian clam Corbicula, as well as freshwater mussels, which are in the order Unionaceae. This order contains three families, the Margaritiferidae (2 genera), the Amblemidae (9 genera), and the Unionidae (34 genera). In North America, Burch (1973) recognizes 221 species of mussels belonging to the Unionaceae. The genera which are included in each family of this order are listed in Table 2-1.

Anatomy of the Shell

The shell

10. All freshwater mussels are equipped with a bivalved shell composed mainly of calcium carbonate. The shell is divided into a left and right half and is held together dorsally by a ligament (see Figure 2-1) which usually remains intact (so the shells stay connected)

after the organism dies. The ligament is composed of conchiolin, a horny proteinacious organic material; when the two valves are closed, the ligament is flexed and constricted. When the animal dies or when the internal muscles are relaxed, the ligament also assumes an unflexed, relaxed position which causes the shell valves to open.

11. The shell of a freshwater mussel consists of three discrete layers. The outermost part of the shell is a thin organic layer termed the periostracum and, less commonly, the epidermis. This, like the hinge ligament, is composed of conchiolin. The periostracum ranges in color from yellow (yellow sand shell, Lampsilis anodontoides) to brown (mucket, Actinonaias carinata) to black (black sand shell, Ligumia recta) to green (juvenile Arcidens confrugosa and Leptodea laevissina). In some species, conspicuous green rays (rainbow shell, Villosa iris) orginate from the dorsal aspect of the animal and run ventrally to the edge of the shell.

12. The external surface of the shells can be smooth (the floaters, Anodonta spp. or paper shell, Leptodea spp.) or covered with knobs or pustules (members of the genus Quadrula). The giant washboard (Megalonaias gigantea) and three ridge (Amblema costata) have a series of conspicuous undulations or ridges on the shells. The maple leaf (Quadrula quadrula) exhibits a shallow to deep groove or sulcus beginning at the umbo and running to the ventral edge of the shell. On some species (Leptodea laevissima, Proptera alata), the shell protrudes dorsally into a broad, flat wing.

13. The periostracum protects the underlying calcium carbonate from the erosive action of moving sand and gravel and the corrosive character of low pH water. Occasionally, living specimens have been found with the periostracum worn and the shell eroded and corroded so deeply that the internal soft parts were exposed. The color of the periostracum can vary slightly depending on water quality and possibly other environmental conditions. Sometimes the color appears to be part of the shell; however, the dark substances can usually be scrubbed clean with a stiff brush or scouring pad (see Part VII). Beneath the periostracum is a middle prismatic layer of crystalline calcium carbonate. This layer is relatively thin in most species.

14. The innermost and usually thickest layer of the shell is termed the nacre or mother-of-pearl. This layer is made up of a series of thin calcium carbonate plates which lie on top of each other and parallel to the surface of the shell. The nacre can vary from bluish white (three ridge) to light salmon (certain pigtoes in the genus Pleurobema) to purple (Elliptio crassidens). The entire nacre, or certain portions of it, is often iridescent. As with the periostracum, color of the nacre can be variable. For example, in the Buttahatchie River in eastern Mississippi the pistol grip (Tritogonia verrucosa) was found exhibiting either white or purple colored nacre. In addition, however, the color and texture of the nacre (as well as the periostracum) do have taxonomic significance in many species. For this reason, many malacologists hesitate to use any preservative techniques on these shells (see Part VII).

15. On the upper or dorsal aspects of the inside of the shell there are lateral and pseudocardinal teeth separated by a broad-to-narrow flat area known as the interdentum. All three of these features are points of apposition for the two shells and help to hold them securely together; they are features of taxonomic significance in many species. The lateral and pseudocardinal teeth are robust in the three ridge and entirely absent in the floaters (Anodonta grandis); the fragile paper shell (Leptodea fragilis) has very reduced pseudocardinal and lateral teeth. We have observed that the heavier, thick-shelled specimens, because of stronger teeth and muscles, can withstand drying conditions and other perturbations more readily than the thin-shelled species (see Part XI and XII).

16. Ventral to the interdentum and pseudocardinal teeth is a shallow or deep depression termed the umbonal cavity. The umbones which appear as external swellings are externally visible and represent the oldest part of the shell. The umbonal cavity is pronounced in the ebony shell (Fusconaia ebena) but very shallow to nonexistent in its look-alike, Status Review* species from the Mobile River Basin (Alabama and

* The U. S. Fish and Wildlife Service is collecting information on this species to determine if it should be included on the list of Endangered Species.

Mississippi), Pleurobema marshalli. Along the ventral margin of each shell is a wavy depression or line. This pallial line, which roughly parallels the edge of each shell, represents the point of attachment of the edge of the mantle to the shell.

17. On the inside of both shells are scars where the muscles were attached. The large posterior and anterior adductors draw the shell together; the smaller anterior and posterior retractors draw the foot into the shell. The anterior protractor, which is posterior to the adductor, helps to extend the foot (see Figure 2-1).

Internal Anatomy

18. The various features of the soft anatomy or viscera will not be discussed in detail in this report. The previously referenced textbooks and papers on mollusca contain fairly detailed information on this topic. The dorsally located (see Figure 2-2) visceral mass contains the kidney, stomach, heart, etc. On either side of this mass lies a thin double gill which runs the entire length of the organism. Exterior to the gills is a thin translucent sheet of tissue termed the mantle. The innermost fold of the edge of the mantle secretes the prismatic and nacreous shell layers, while the middle fold is sensory in function. The entire outer fold of the mantle participates in the secretion of the mother-of-pearl or nacre. All of these features are easy to identify without a microscope (see Part VII for techniques for relaxing and preserving these organisms).

Gills

19. The gills in mussels function in gas exchange, feeding, and in the females as a marsupium for developing eggs. It is possible to pry open mussels and observe the glochidia on the gills of gravid females.* When water enters the mantle cavity by the incurrent orifice, it is pulled into the ostia (holes) of the gill by action of cilia.

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* The spring is the best time to observe this, although some species do not contain glochidia until mid- or late summer.

Water then moves through the water tubes located in the gills where gas exchange takes place. Additionally, food particles are trapped by mucus secreted by the gills. This food is moved ventrally by cilia and is eventually passed anteriorly to the labial palps. Food is sorted from inorganic debris by the labial palps and enters the mouth. When captured mussels are placed in a tank or bucket, a mucus string is sometimes noted protruding from the ventral portion of the shell. This string carries the inorganic particles not passed to the mouth but ejected out of the body.

Mantle

20. The mantle is a thin sheet of tissue on the outside of the viscera, which secretes the shell. The space between the mantle and the viscera is termed the mantle cavity. Pearls are created by secretions of nacre when a foreign particle becomes trapped between the shell and the mantle. The mantle is sealed dorsally, but it forms low folds which envelop the animal and remains open anteriorly, ventrally, and posteriorly. The posterior portion of the mantle forms the incurrent and excurrent siphons. Although the main function of the mantle is to secrete the shell, there are blood vessels throughout this organ for limited exchange of gases. Finally, cilia on the epidermis of the mantle aid in trapping food in mucus and passing a string of food to the labial palps.

Natural History

Behavior

21. Mussels orient themselves with the anterior portion (the swollen part with the umbones) buried into the substrate. The partially opened valves are directed into the current to facilitate circulation of water and food. In the living organism, the incurrent and excurrent orifice, one or both ringed with cilia, are readily visible. The incurrent opening is the largest of the two and admits water, food particles, dissolved oxygen, and, in the female, sperm. The excurrent or anal orifice is a point of exit for water containing waste and, in the females, the immature forms or glochidia. A supra-anal opening, which aids in

the discharge of water when the valves are suddenly closed, is located dorsal to the excurrent or anal opening. When a live mussel is abruptly extracted from the substrate, the foot retracts and the valves close, which forces a stream of water out the excurrent openings.

Feeding

22. Mussels are filter feeders; they take in water and remove particulate organic matter and algae. Churchill and Lewis (1924) found Volvox, Pleodorina, Microcystis, filamentous algae fragments, Euglena, cladocerans, various protozoa, organic detritus, and sand grains all in the stomach of Lampsilis luteola (=L. siliquoidea). This material moved through the alimentary tract in about 1 hr. Bovjerg (1957) conducted feeding experiments with Lampsilis siliquoidea and demonstrated that mussels moved about substantially more when food was scarce.* Under laboratory conditions mussels moved very little when the water contained organisms such as Volvox, Eudorina, Pleodorina. Coker et al. (1921) discussed feeding in mussels and reported that this process may be non-discriminatory; they found that the relative percentages of kinds of food in mussel stomachs and in surrounding water tended to be approximately the same. When these workers conducted a series of feeding experiments, they demonstrated that the organisms readily took most plant material but refused fish blood, meat, and other animal products. Allen (1914) reported that mussels filter about a litre of water every 42 min, although this figure is no doubt variable depending on environmental conditions, size, age, and species being studied.

23. In mussels the mouth lacks masticatory structures, and the labial palps pass food directly to the stomach. There is a digestive gland, intestine, rectum, and anus present in these organisms; a crystalline style, which is an elongated rod, is located within the diverticulum of the stomach and appears to be specific in the digestion of carbohydrates. Undigested material passes through the intestine and out the anus into an area near the excurrent opening. From this point,

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* Commercial shell fishermen often describe mussels moving about in search of food.

wastes are swept out of the animal by circulating water from the excurrent syphon.

Nitrogenous waste

24. In the freshwater mussel the kidney is located immediately below the heart. One end of the kidney opens into the heart; pericardial fluid is filtered and nitrogenous waste and salts are removed as necessary to maintain the internal isosmotic balance of the animal. From the kidney, wastes are discharged into the suprabranchial gill chamber and passed out the excurrent orifice.

Circulation

25. The circulatory system consists of a heart composed of one ventricle and two auricles surrounded by a pericardial cavity, arteries, and veins. Blood is pumped out of the arteries and through the anterior and posterior aortae to the rest of the body. Blood moving to the gills and mantle is oxygenated before it is returned to the heart. This is known as an open system since blood circulates freely and is not always restricted to vessels.

Nervous system

26. Various areas of the mantle are sensitive to light; when shadows are cast over these animals they typically stop feeding and close their valves.* There is a statocyst near the pedal ganglia in the foot for balance, and chemotactic sense receptors are located around the labial palps to detect food. Two main central ganglia located near the mouth and on each side of the visceral mass send impulses to the foot, viscera, and tissues.

Reproduction

27. Male Ohio River pigtoes (Pleurobema cordatum) produce sperm throughout the warmest months, although April appears to be a peak month (Yokley 1972). The mature spermatozoans are elongate rods rounded on one end and slightly concave on the other end where a flagellum protrudes. In the female the gonopores are located anterior to the kidney.

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* While unexpected closure does not have any effect on mussels collected using hand techniques, it can influence brailing techniques, see Part III.

The eggs are released from the ovaries and carried to the outer gills, probably by water currents. The eggs come to rest on the outer gill where they will be fertilized.

28. The pigtoe is termed tachytictic; i.e., fertilized eggs are retained in the parent for only part of the summer. In the so-called long-term breeder (bradytictic) the young are incubated for most of the year and are usually released in early summer. In the pigtoe, the sperm are carried into the female then moved to the eggs on the outer gill where fertilization occurs. This all takes place in the early spring, and the young are released within several weeks.

29. The fully developed embryo, or glochidium, of P. cordatum is small and hookless and measures 0.14 to 0.15 mm in length. It is similar to an adult except that it has a single adductor muscle and no byssal thread*. The processes of spermatogenesis and glochidia release are temperature dependent. In the vicinity of Muscle Shoals, Alabama, on the Tennessee River, Yokley (1972) found that temperature had to reach at least 20°C before embryo development occurred. During June of 1967, mean water temperatures were 23°C; at that time the percentage of gravid females was the greatest.

30. Glochidia are released from the female through the excurrent siphon. To survive and produce an adult, this motile larva must attach to an appropriate fish host for further development. In the case of P. cordatum, the appropriate fish host was determined to be the rosefin shiner (Notropus ardens). In his work, Yokley (1972) noted that glochidia were evenly distributed over the gills and a hundred or more glochidia could be found on each side of a fairly small fish causing no apparent injury. However, under laboratory conditions where high concentrations were attained, microscopic examination of the gills showed that many of the glochidia had clasped so tightly onto the filaments that they pinched and closed small blood vessels and interrupted the flow of blood.

31. After about the 14th day, the parasitic juvenile of P. cordatum drops off the gills or the body surface of the fish.

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* Strong, horny thread to hold the young mussel in place.

The period of time spent on the fish appears to be necessary for transformation of the glochidea or immature stage to the juvenile or young adult stage; evidently, the fish provides the necessary nutrients and stimulants to allow this to take place. For a time after leaving the fish, the young mussel is practically nonmotile and subject to a high mortality rate; if it drops off the fish at a place with unsuitable substrate, water chemistry, or flow, it will certainly perish.

32. If mussels are kept in an aquarium, it is not unusual to observe release of glochidia. If fish are present, the glochidia will often attach to the gills, fins, or body surface and to the naked eye will look like small black dots. Mr. Billy G. Isom* reported that freshwater mussel glochidia have been known to successfully infect guppies, which are tropical fish.

33. In a recent study in Virginia, Zale and Neves (1982) reported on the reproductive biology of four species of mussels in the subfamily Lampsilinae (Villosa nebulosa, V. vanuxemi, Medionidus conradicus, and Lampsilis fasciola). They found that for these species, active gametogenesis occurred throughout the year, although spawning periods were at different times in the spring and summer. Glochidia took from 7 to 8 weeks to develop following fertilization. Using 130-µm mesh drift nets, they were able to collect up to 100 glochidia (visible after exposure to rose bengal stain) throughout the year.

Locomotion

34. As indicated by the Greek derivation of their class name Pelecypoda, these organisms have a hatchet-shaped foot. This muscular structure is extended between the shells and functions as both a locomotory and hold-fast organ. When a mussel is pulled quickly from the substrate, the foot is usually observed to be extended several centimetres out of the shell. Using the retractor muscles, the organism pulls the foot back into the shell within a few seconds. When muscle relaxants are used (Part VII), the shells gape and the foot protrudes

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* Personal Communication, August 1981, Billy G. Isom, Biologist, Tennessee Valley Authority, Muscle Shoals, Ala.

out between the valves. Tracks of mussels in sand can easily be observed in shallow water in lakes and streams as well as in an aquarium. Often when water levels drop, mussels (as evidenced by their tracks) appear to move to deeper water.

35. Mussels initiate movement by first extending the foot into the substrate. Internal sinuses in the foot slowly fill with blood so after the foot is extended the terminal end swells and anchors in the substrate. Next, the retractor muscles contract and pull the organism slowly forward. Mussels can be so firmly anchored in gravel bars that it takes considerable strength to extricate them by hand. The brail, possibly because of the slight elastic jerk accompanying its mode of operation, appears to extract tightly anchored mussels with little difficulty. The brail operator can usually feel tugs on the rope which indicate mussels are being pulled out of the substrate by the hooks.

Growth

36. Increases in thickness of the shell is a result of secretions from all over the mantle. Increase in overall size (length, etc.) of the shell is accomplished by secretions along the ventral and lateral aspects. Based upon data from studies of the fauna of the Mississippi River and vicinity, (Coker et al. 1921), increases in length of freshwater mussels vary from 1.5 to 2.0 in. per year in thin-shelled species and from about 1 to 1-1/4 in. per year in the thicker shelled species. In the Saint Francis River, Arkansas, six or more years were required for the yellow sand shell to obtain a size of 5 in. (Coker et al. 1921).

37. Mussels can be aged by counting the growth rings on the outside of the shell. The ring is actually a dark band on the shell and indicates a time when the mantle retracted and growth of the shell ceased. When conditions become favorable, the mantle extends and the prismatic layer "splices" into the older section of the shell. Coker et al. (1921) refer to this as a duplication or interruption ring, since the dark band actually indicates a time when growth ceased. Cold weather is only one cause of interrupted growth. It has been observed that simply taking the organisms out of the water can cause a retraction of the mantle and a growth ring. Obviously any environmental

perturbation such as low water, extreme periods of poor water quality, etc., could cause development of a growth ring. For more information on age and growth of mussels see Lefevre and Curtis (1912) Isley (1914), Stansbery (1967, 1970), Coker et al. (1921), and Rhoads and Lutz (1981).

Habitat preferences

38. Mussels are usually most abundant in rivers and streams with good current although lakes and ponds support characteristic species assemblages. Mussels can be separated into groups based upon the types of habitat where they are usually found (see Tables 2-2 and 2-3). Small ponds frequently support large populations of the fragile paper shell Anodonta imbecillus. Other slack water inhabitants include species in the genera Anodonta and Leptodea, although various species in the genus Quadrula and the giant washboard (Megalonaias gigantea) also inhabit lakes. However, certain unionids, like many other aquatic organisms, are often collected in habitats typically considered unsuitable; their mode of dispersal and the tolerance for varying environmental conditions exhibited by certain species account for this.

Table 2-1

Families, Subfamilies, and Genera of Mussels of North America

(from Burch 1973)

Family	Subfamily	Genus
MARGARITIFERIDAE	MARGARITIFERINAE	Margaritifera
	CUMBERLANDINAE	Cumberlandia
AMBLEMIDAE	AMBLEMINAE	Amblema
		Elliptoideus
		Fusconaia
		Plectomerus
		Quadrula
		Quincuncina
		Tritogonia
	GONIDEINAE	Gonidea
	MEGALONAIADINAE	Megalonaias
UNIONIDAE	PLEUROBEMINAE	Cyclonaias
		Elliptio
		Hemistena
		Plethobasus
		Pleurobema
		Uniomerus
	POPENAIADINAE	*Cyrtonaias*
		Popenaias
	ANODONTINAE	Alasmidonta
		Anodonta
		Anodontoides
		Arcidens
		Arkansia
		Lasmigona
		Simpsoniconcha
		Strophitus
	LAMPSILINAE	Actinonaias
		Carunculina
		Dysnomia
		Ellipsaria
		Glebula
		Lampsilis
		Lemiox
		Leptodea
		Ligumia
		Medionidus
		Obovaria
		Proptera
		Truncilla
		Villosa
		Cyprogenia
		Obliquaria
		Dromus
		Ptychobranchus

Table 2-2

Mussels Frequently Collected from Small Streams

In the Ohio-Mississippi Drainage

1.	Amblema costata	8.	Alasmidonta calceolus
2.	Fusconaia flava	9.	Alasmidonta marginata
3.	Pleurobema cordatum coccincum	10.	Carunculina parva
4.	Pleurobema clavum	11.	Actinonaias ellipsiformis
5.	Lasmigona compressa	12.	Micromya iris
6.	Anodonta grandis	13.	Lampsilis fasciola
7.	Anodontoides ferussacianus	14.	Dysnomia triquetra
		15.	Anodonta imbecillus

Table 2-3

Mussels Frequently Collected from Large Streams

In the Ohio-Mississippi Drainage

1.	Fusconata ebenus	12.	Anodonta imbecillis
2.	Fusconaia undata	13.	Obliquaria reflexa
3.	Megalonaias gigantea	14.	Obovaria olivaria
4.	Amblema peruviana	15.	Truncilla truncata
5.	Quadrula pustulosa	16.	Truncilla donaciformis
6.	Quadrula quadrula	17.	Plagiola lineolata
7.	Quadrula nodulata	18.	Leptodea fragilis
8.	Quadrula metanevra	19.	Leptodea laevissima
9.	Tritogonia verrucosa	20.	Proptera alata
10.	Lasmigona complanata	21.	Ligumia recta latissima
11.	Anodonta corpulenta	22.	Lampsilis anodontoides
		23.	Lampsilis anodontoides fallaciosa

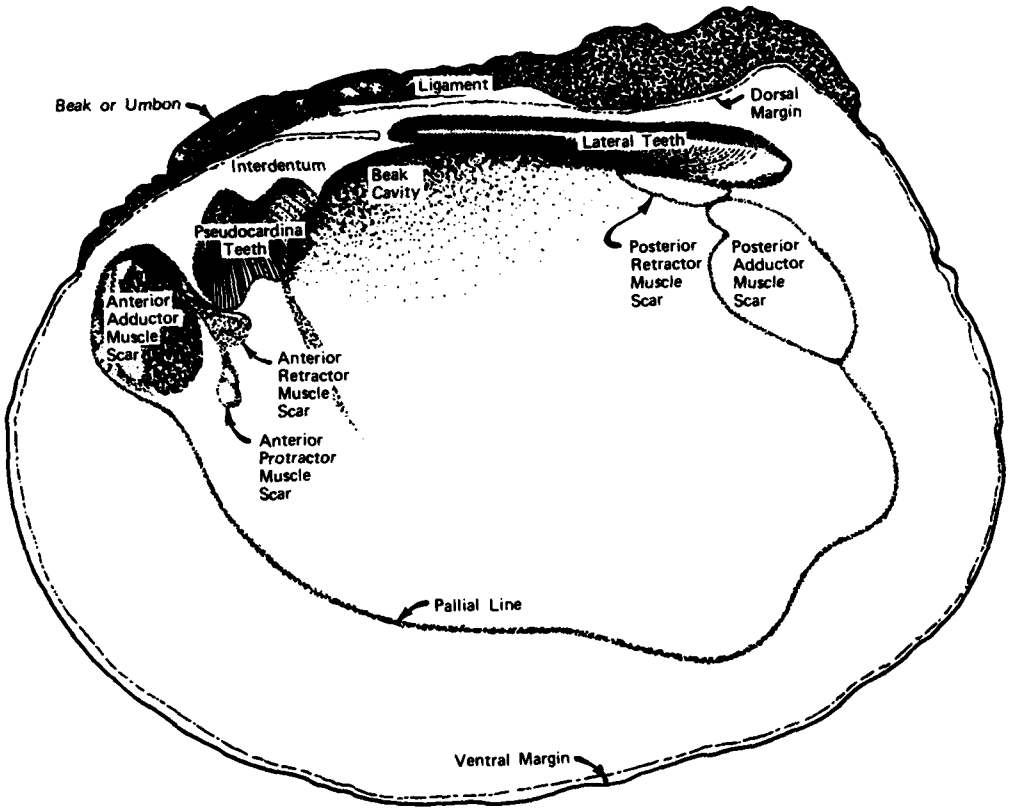

Figure 2-1. Anatomy of a unionid shell (continued)

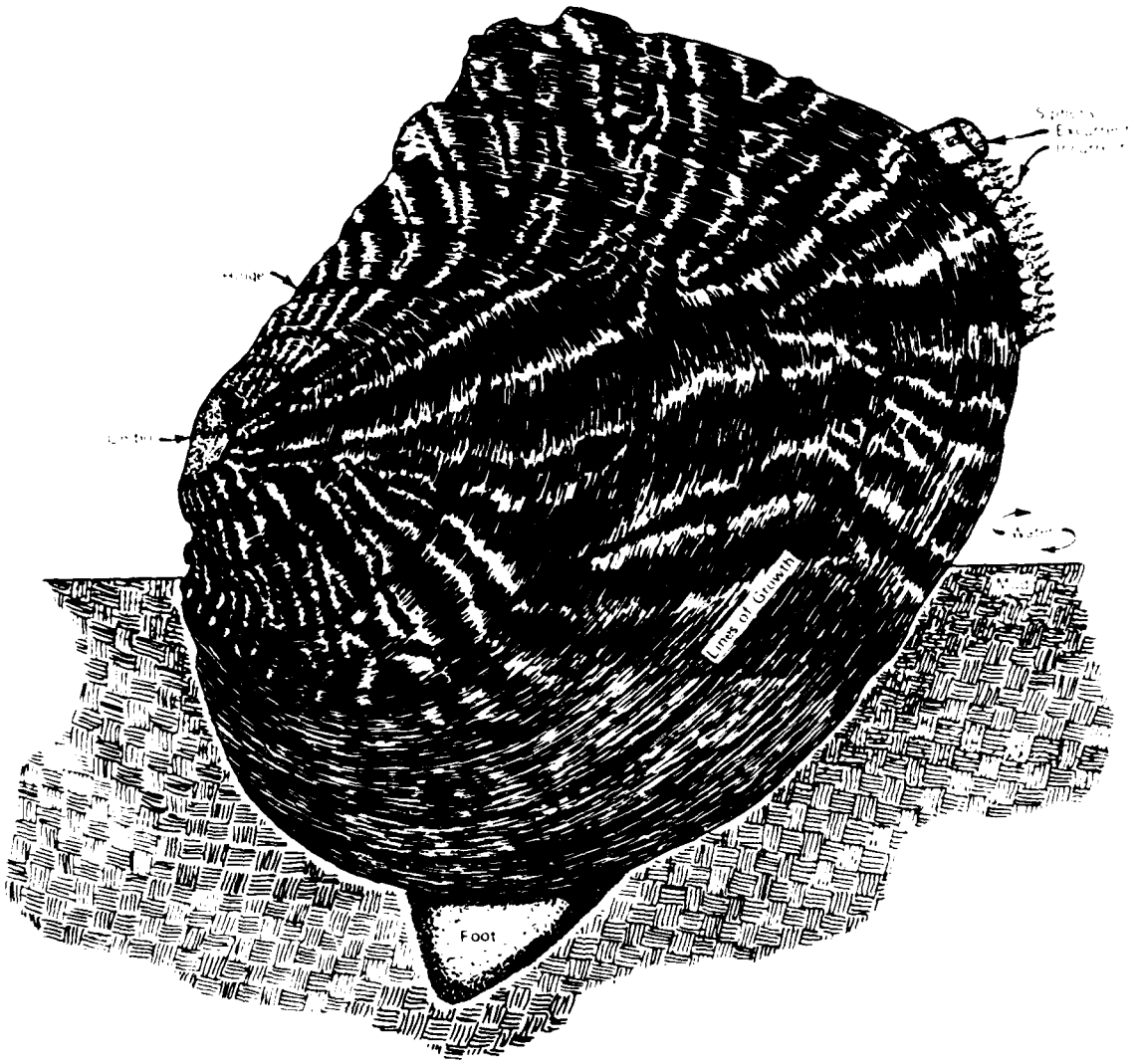

Figure 2-1. Concluded

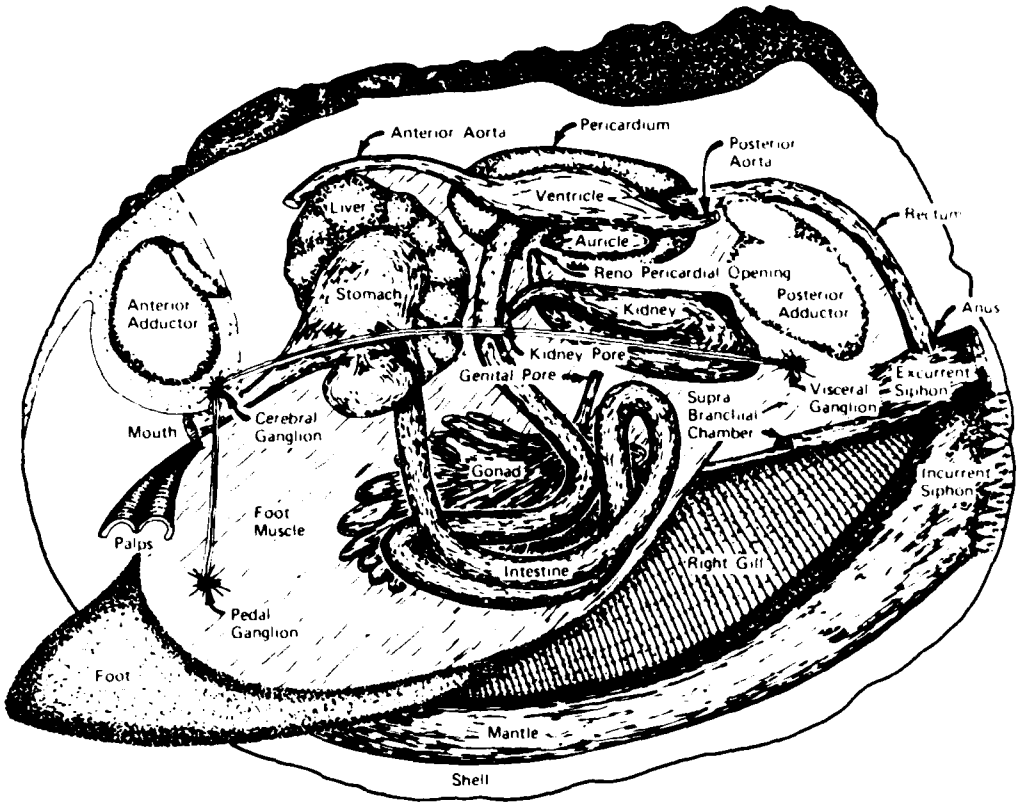

Figure 2-2. Internal anatomy of the freshwater mussel Anodonta (after Storer and Usinger 1957)

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PART III: FRESHWATER MUSSEL SAMPLING

Introduction

39. The U. S. Army Engineer Waterways Experiment Station (WES) has constructed and tested various types of mussel sampling gear. WES has used this equipment under a wide variety of conditions to determine the applicability of each. The following describes briefly how each type of equipment is constructed and how it is used. In most cases this gear can be built with simple tools, a minimum of parts, and a small investment of time. Written instructions for building equipment have been kept to a minimum; it was felt that the majority of these items could be built by reference to photographs, a parts list, and a few brief instructions. See Table 3-1 for a comparative evaluation of mussel sampling equipment and methods. Information presented in this part was obtained from WES experience and the following technical literature: Rasmussen (1980), Brice and Lewis (1979), Jacobson (1974), Starrett (1971), Parmalee (1967), Coker (1919), Bumgarner (1980), Isom (1980), Kraemer and Gordon (1980), and Buchanan (1980). This part deals specifically with construction and use of equipment; Part IV treats the efficiency of various of these gear types.

Permits

40. Both Federal and State permits should be obtained prior to sampling for mussels. The State permit, if applicable*, is obtained from the State Wildlife Agency and is needed for any vertebrate or invertebrate sampling. Usually the permitting agency requires a written record of the organisms collected from each area. A Federal permit is available from the Office of Endangered Species, U. S. Fish and Wildlife Service, Washington, D. C., and is required if the objective of the

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* Some states do not require permits for invertebrates.

survey is to search for endangered species. Allow at least 6 months to obtain the permit; no unique requirements or conditions are necessary.

The Brail

Background

41. The brail, or crowfoot dredge (Figure 3-1), has been in use since 1897 (Coker 1919). In the past it was used primarily by commercial shellfishermen to obtain large quantities of live mussels for the manufacture of pearl buttons. The brail is still used in flowing waters in the United States for mussel harvesting; now shells are used primarily for the production of cultured pearls. Today, however, most freshwater mussels are obtained for commercial purposes by divers using SCUBA equipment.

Description of the brail

42. The brail bar is made from either wood or iron and can vary in length from 2 to 20 ft. Hooks are attached to the bar with a short length (about 12 in.) of small chain or nylon cord. A 10-ft-long bar with 40 chains and a total of 200 hooks was considered a "standard" size for use in the upper Mississippi River (Bumgarner 1980). This size is about the maximum length that can be handled by an average person without a winch. From 1 to 8 crowfoot or dovetail hooks (Figure 3-2) are secured to each chain. The crowfoot, or mud hook digs into soft substrate and can extract deeply buried specimens. The dovetail, or rock hook slides over obstructions and will not dig into the substrate. A bead, which helps to hold the mussels when captured, is usually applied to the tip of each hook with an acetylene torch. A pair of ropes from each end of the bar, plus a center safety chain, are fastened to a metal ring to form a bridle. A tow line consisting of a variable length of 1/4-in. rope is secured to the metal ring of the bridle and is used to pull the brail through the water.

Operating the brail

43. The brail is operated for a specified time (usually 10 min) or distance by towing it from the bow of a small to medium-sized boat.

The boat should move in reverse and as slowly as possible. In the past commercial clammers powered their boats with a "mule," a form of underwater sail which makes use of the current to pull and steer the boat (Coker 1919, Emanuel 1980). The brail captures mussels that are oriented upstream, partially buried in the substrate with the valves slightly open. When a hook slides between the shells, the soft tissue of the organism is irritated and the anterior and posterior adductor muscles rapidly contract, bringing the shells together to hold the hook securely. The organism is then jerked out of the substrate and remains on the hook until the brail bar is brought into the boat and the mussels removed.

44. It is best to use two people when brailing for mussels: one to operate the boat, the other to manage the tow line. The tow line should be secured to the bow of the boat, although the tow line operator should keep a hand on the line to check the operation of the bar. On gravel/cobble bottoms the hooks frequently catch and snag; over coarse sand/small gravel a light vibration or general tugging is noted; in mud/silt a continuous pull is felt. If no resistance is apparent, the bar and hooks could be above the substrate. Additional weight on the bar or a slower operating speed will correct this problem. Adding lead weights, metal bars, or additional chains and hooks, as well as soaking a wooden bar, will all effectively decrease buoyancy. On the other hand, if the bar is too heavy, it can drag on the substrate and cause the mussels to close before the hooks reach the organisms. It is sometimes necessary to pull a brail through a bed several times. Commercial clammers frequently work an area many times in a day. Usually the exact path of the hooks across the bottom is never duplicated.

45. The mussels clamp down on the hooks very tightly. If properly caught there is probably little chance that the specimens will fall off before the bar is hauled up into the boat. WES personnel have noted that mussels will remain on the hook for up to 4 hrs when suspended in an aquarium. In the field the specimens can be removed by gently twisting or tugging. A reversing set of pliers (Figure 3-3, Table 3-2), made

by modifying O-ring pliers, is useful for extracting mussels from beaded hooks and ensures that there is no damage to the shells.

46. Commercial clammers often speak of mussels as "biting" in reference to catching mussels. Emanuel (1980) reports that mussels were taken much more readily in the morning before 10:00 a.m. and in the afternoon after 3:00 p.m. until dark. A number of authors report that mussels become less active or dormant in coldwater temperatures and are rarely captured (Coker et al. 1921, Matteson 1948, Parmalee 1967, Emanuel 1980). Freitag (1978a) reports that in the upper Mississippi River mussels ceased to respond to brailing below temperatures of 50 to 55°F. Mussels have been reported to stop feeding when the water becomes excessively turbid because of storm or flood conditions (Coker et al. 1921, Jones 1950). Emanuel (1980) reports that mussels "bite" poorly when disturbed by boat passage. In addition, mussels appear to be more likely to fall off the hooks when water temperatures are low. Since it is understood that not all biological surveys can be conducted at appropriate times, the above information should be taken into account when reporting results.

Construction of the brail

47. Any standard 2-in. by 4-in. board* can be used for a brail bar, although oak, ash, cypress, or other hardwoods are the most sturdy and hold up well under harsh use. Along the leading edge of the wooden bar attach 1-3/4-in. screw eyes at 3-in. intervals for the chains (Figure 3-4, Table 3-3). To each screw eye secure one "S" hook, then a 12-in. length of chain or nylon cord. Kessler (1982) prefers the more flexible nylon cord instead of the chains. He feels that the cord dampens the abrupt jerking motion of the hooks when they are being dragged through coarse substrates. In place of the screw eyes, many commerical shellfishermen attach the chains (or cords) to the bar directly with stout 1-1/4-in. fence staples (horseshoe-shaped nails).

* Commercial mussel fishermen in Indiana use a 10- or 12-ft piece of galvanized water pipe with cords rather than chains to secure the hooks. Although this apparatus is different from the one described here, it works very well.

When this is done a length of No. 16 wire is usually threaded through the first length of all chains then secured tightly to each end of the bar. Instead of attaching the chains directly to screw eyes via the "S" hook, WES uses a quick-release snap clip. This allows rapid removal of each chain from the bar for transportation or to change the size of hooks quickly.

48. On the edge opposite the small screw eyes attach three 6-in.-long screw eyes: one at the balance center, one each at the other two ends about 2 in. from the end of the wooden bar. To form the bridle use 1/4-in. rope (Figure 3-1) for each end and a 2- to 3-ft length of light chain for the center. To the bridle ring tie a tow rope; from 30 to 50 ft is usually sufficient.

49. WES has found brail hooks to be simple and inexpensive, although time-consuming, to build. Cut a 16-in. piece of stiff wire (0.045 to 0.063 in. in diameter), and place a loop in the center (Figure 3-5, Table 3-4). Hold this wire by its loop in a vise and thread a second wire of equal length through the first loop. Pull the second wire tight with vise grips. While the wires are still in the vise, bring the four ends together; then remove the partially constructed hook, turn it over, and hold it again in the vise, this time by the four ends. After twisting the wires together wrap the lower part of the hook with about 12 in. of No. 16 wire. Spread the ends of the hook and place a bead on each wire with a torch. Attach five hooks to each chain: one at the end, the others 2 to 3 in. apart.

50. Coker (1919) describes making hooks by using an iron plate or strap with drilled holes as a template. The cut lengths of wire are bent into "needle" or "hairpin" shapes and held by inserting the free ends through the holes in the iron strap. This serves to secure the wires while the hook is twisted, tied, and trimmed. Mr. R. Julian, U. S. Fish and Wildlife Service, East Lansing, Michigan, has made hooks using the vice and the iron strap. He has found the latter technique is easier, although he cautions that it works best if the wires are lightly lubricated first.

51. A brail is an effective device in flowing waters too deep to wade, with sand, mud, or gravel substrate (Table 3-1), although it will snag easily on brush, large rocks, and trot lines. A brail is not the best device for nonflowing water, since mussels are oriented in many directions under these conditions. The device is best employed in small to large rivers with adequate flow and bottoms fairly clean of brush, stumps, and other large debris.

52. The brail is a reconnaissance device. It is neither qualitative nor quantitative. Specimens buried beneath the substrate, or in crevices between rocks, will be missed. Mussels much smaller than 2 in. in length are usually not taken, although it is possible to snare juveniles of many species by their byssal threads (Freitag 1978b).

53. It is important to realize that, because of low efficiency, many brail runs can yield negative results, even though mussels are actually present. Fuller (1978) made 1959 5-min-long brail runs, of which only 1035 (53 percent) were positive. His 10-ft-long bar had an average of 7.2 mussels per positive brail run (a range of 1 to greater than 14). Freitag (1978b) made 132 5- to 10-min runs and had an average of 3.1 mussels per positive sample (a range of 1 to greater than 30). Both Fuller's (1978) and Freitag's (1978b) surveys were conducted in areas of high sand deposition, which were proposed for dredging. Thiel et al. (1980) report a mean total of mussels per brail run (catch per unit effort) using a 10-ft bar ranging from 0.3 to 2.5 for pools in the upper Mississippi River.

The Dip Net or Danglade Dredge

Background

54. In 1911, commercial shell fishermen devised a sturdy dip net for collecting mussels in Peoria Lake, Illinois. The apparatus they constructed efficiently collected mussels where scissor tongs, oyster tongs, rakes, and crowfoot hooks had previously proved unsuccessful (Danglade 1914). This dip net, or Danglade Dredge as it is sometimes called, was still an important commercial mussel fishing device on the

Illinois River in the mid 1960's (Starrett 1971). Starrett used this apparatus for his 1966 survey of the Illinois River and reported taking 885 live mussels in 74 separate collections. In addition, he used the dip net to make 57 quantitative samples in a 400-ft marked area where water depths ranged from 5.0 to 14 ft and averaged 9.8 ft deep. The Danglade Dredge efficiently took all mussels greater than 1.5 in. long. It missed, however, the mud-burying slough sand shell (Lampsilis anodontoides fallaciosa). Starrett found that the dredge could be fished for only a minute or less because the net became filled with debris, rocks, and shells. Because of this he concluded that the dredge was best used as an exploratory device.

Construction

55. The Danglade Dredge (Figure 3-6, Table 3-5) can be constructed in 6 to 12 manhours; total materials can cost about $100, although if scrap iron and other spare parts are obtained, this figure can be considerably reduced. The main part of this dredge is a 1/4-in. by 3-in. flat iron plate bent into a hoop semicircular to triangular in shape. The top of the hoop is bolted to an aluminum or hardwood timber 8 or more ft long. A wooden 2-by-4 is cheaper and easier to acquire, although an aluminum bar is more sturdy and less prone to crack. The base of the hoop is flat, varies from 12 to 20 in. in total length, and has coarse fingerlike tines on its leading edge. These tines can be made from 6-in. by 1/4-in. rebar and should be bent downward at a 10- to 20-deg angle. A net with 1/2-in. to 2-in. mesh size, depending upon the substrate type and size of mussels to be collected, is secured to the hoop. A short bridle made from chain or sturdy rope can be attached to the two sides of the dredge. A single rope connecting a bridle to the boat is used to help pull the sampler through the substrate. Depending on how it is operated, two sets of lines, one attached to either side of the hoop, can be used in place of the bridle to move the dredge.

Use of the dip net dredge

56. The dredge can be towed from the bow of a small to medium-sized boat moving slowly in reverse. A pair of ropes are secured to both sides of the stern, extend under the boat, and are attached to

either side of the dredge. The operator or tender stands at the bow and helps to guide and raise or lower the dredge. To allow up and down movement, the pole should be loosely secured to the bow of the boat via a loop of rope or a yoke.

57. Starrett (1971) described operating the dredge from the stern of a small boat. A single line connected the dredge to a boom extending laterally from the bow. The yoke was attached to the side of the boat to provide support and allow the handle to move freely. WES personnel have experienced some success with the apparatus by using it from the stern of a small boat in tow by a larger boat. The dredge was secured to the stern of the lead boat by a line running beneath the boat being towed. While this method required two boats, it provided the easiest transit for handling the dredge.

58. Because of its mode of operation, the dip net dredge captures mussels regardless of their size and orientation. In a comparative study conducted in the upper Mississippi River by the U. S. Army Engineer District, St. Paul, this dredge routinely retrieved up to 10 times the specimens captured with a brail. Both devices were used for equal lengths of time and in similar substrate conditions. It was noted that the dip net worked best in mud/sand/small gravel bottoms (Table 3-1) and was inefficient where there were large rocks, stumps, or other debris. It can, however, be fished for only a minute or so before it has to be brought into the boat so the net can be cleaned and checked. In addition, the metal tines are destructive to the substrate and frequently puncture the valves of thinner shelled types belonging to the genus Anodonta.

Grab Samplers

Background

59. There are quite a number of standard grab samplers (Figure 3-7) available for collecting benthic samples. The lighter Ekman dredge works best in soft mud or silt. The Petite Ponar and standard-sized Ponar sampler will operate more efficiently than the lighter Ekman

in sand and gravel. The Peterson sampler, which takes 2 sq ft of sample, will collect fairly well in high-velocity water when the substrate consists of gravel. This dredge is cumbersome and heavy and requires a winch to operate. The larger Shipek can only be operated from a fairly large boat, and a winch is a requirement; it will sample well in hard bottoms with high-velocity currents.

Use of grab samplers for mussels

60. As described in Part II, mussels are usually found concentrated in very discrete beds. They can be quite numerous, ranging from 75 to 100/sq m, although densities less than 5/sq m are not uncommon. It should be apparent that even the Peterson dredge which takes a 2-sq-ft sample can easily miss mollusks which are in low concentrations. It should be noted that M. Ellis in his 1930-31 survey of the upper Mississippi River collected mussels with a "self closing dredges which covered 6 square feet of river bottom ..." (van der Schalie and van der Schalie 1950). However, the lightweight Petite Ponar and Ekman dredge may fail to close properly on large mussels. While bivalves are frequently retrieved using grab samplers, WES experience does not show this type of sampler to be a suitable device for searching for mussels. Grab samplers are often used to make quantitative samples in mussel beds, but when this is done their limitations should be kept in mind.

61. When conducting a mussel survey, WES prefers to use a Petite Ponar (Figure 3-7) as a reconnaissance tool (see Part V). It is lightweight and generally takes a good sample where mussels are common. WES used the Petite Ponar mainly for collecting sediments samples to characterize habitats. Collected samples can be visually characterized (mud/sand/gravel, etc.) on the spot and/or the samples returned to the laboratory for detailed particle-size analysis. If substrate is visually characterized while in the field, the collecter can (a) ensure that he knows precisely the type of habitat being studied and (b) quickly identify other areas which may be suitable for sampling by other means. For more information on substrate evaluations as a part of mussel-sampling programs, see Harman (1972) and Sickle (1980).

The Mechanical Dredge

62. A variation on the dip net dredge is a mechanical dredge which is a rectangular box with mesh sides. Along the leading edge are rounded rakelike teeth which dig into the substrate and help scrape everything into the box. This device is dragged with a cable from the stern of a fairly large boat. When full of mussels and substrate, the box is pulled out of the water and its contents are dumped into the boat. Like the dip net, this apparatus can be considered quantitative, although estimating the size of an area sampled is often difficult. The mechanical dredge is heavy and requires a powerful boat and winch for operation. It is destructive to the substrate and the fauna. The apparatus has utility for collecting large numbers of organisms for commercial purposes. The mechanical dredge is easier to operate than the previously discussed dip net dredge if proper equipment is available.

Hand Collecting

Background

63. WES has built and tested a variety of equipment to aid the collector while searching for mussels in shallow water. All of this gear is fairly easy to construct, inexpensive, and simple to use and can be employed while wading or from a small boat. None of these devices is quantitative, but all are aids for the scientific investigator who is trying to observe and collect mussels. Additional types of gear which can be used for collecting mussels as well as other benthic organisms are sold by Wildco Supply Company, Saginaw, Michigan, or Turtox, Chicago, Illinois.

The basket dredge

64. Background. Dr. C. F. Chang of the University of Taiwan, who was investigating the possibility of exporting freshwater mussels from the United States as a food source, brought to WES a device (Figure 3-8) for collecting freshwater mussels in soft substrates. This dredge or basket sampler can be constructed from bamboo and is still used in the

Orient to collect mussels for food. The dredge weighs about 3 kg; the base measures 40 cm wide by 32 cm deep by 12 cm high. A wooden pole 1.2 m long (in this case a broom handle) is secured in two places to the iron frame with heavy twine. Heavy rods are attached to the base (0.3 cm in diameter) as well as to the back and sides (0.15 cm). The rods on the base, sides, and back are about 1.0 cm apart and are secured to the iron frame with three sizes of wire: No. 20, No. 14, and No. 12.

65. Operating the dredge. This sampler is pulled by the operator towards himself through sand/gravel or silt/mud substrate. It is not effective in coarse gravel, hard-packed material of any consistency, or in areas where there are large rocks, sticks, or other debris. Because the dredge is lightweight it does not effectively dig into hard-packed gravel; in addition, large sticks and rocks bend the leading edge of the rods. After each pull through the substrate, the basket is rinsed by being shaken in the water. The efficiency of this dredge results from its mode of operation: the depth of penetration and speed can be precisely regulated, and all material is easily swept into the basket for sifting. When a dip net from a boat is used, the speed, amounts of substrate samples, and overall efficiency of the operation are difficult to determine. When this small hand sampler is used and the length of the pull through the bottom (typically about 1 m) and the width of the basket opening are known, rough estimates of the number of mussels per unit area can be made.

66. Constructing the dredge. The dredge pictured at the top in Figure 3-8 would be very expensive and time-consuming to construct in the United States because it requires labor-intensive work with various sizes of wire. Using different procedures and materials (Table 3-6) WES personnel have constructed the second dredge shown in Figure 3-8, a device similar in size, shape, and mode of operation to the basket dredge made in Taiwan. The WES dredge, which weighed 2.7 kg without the handle, was assembled by welding 0.30-cm-diameter rods to the 0.5-cm-diameter iron frame. Hardware cloth (with 1-cm mesh size) was secured with No. 20 wire to the back and sides of the basket. The rods on the base should be parallel to the direction that the sampler is pulled.

Since the rods protrude forward, their leading edge must dig into the bottom, and it is important that they be fairly heavy and well-fastened to the iron frame. The WES-made sampler required about 6 manhours to build and cost less than $50 for materials. Using scrap materials would lower the costs considerably.

Modified garden rake

67. A standard garden rake (Figure 3-9, Table 3-7) can be modified by attaching flexible mesh netting or a hardware cloth screen basket. An individual can sweep mussels as well as large snails and occasionally fish, crayfish, or large invertebrates into the net or screen by briskly raking the substrate. Rakes work well in sand, mud, and small-size gravel and poorly where there are large rocks, fallen timber, and other debris. The net is easier to make and less bulky than the hardware cloth basket. Both types of rakes are equally effective, although collected specimens are easier to remove from the more sturdy wire screen basket than they are from the flexible netting.

Modified pitchfork

68. Mathiak (1979), see (Figure 3-10, Table 3-8) used a pitchfork equipped with hardware cloth for collecting mussels in a survey of Wisconsin streams. In addition to helping where the footing was insecure and protecting him from dogs, this device was particularly useful in coarse hard-packed gravel where there were large rocks and other debris. Live specimens can be pried loose from between rocks and dug out of gravel. The wire screen helps hold large and small specimens for removal by hand or until they can be dumped into a bucket or placed on shore.

See-through bucket

69. The see-through bucket* (Figure 3-11, Table 3-9) is made by cutting out the bottom of a 5- or 3-gal plastic pail and replacing it with clear plexiglas. The plexiglas can be secured with silicone

* A wooden box can be fitted with either glass or plexiglass; in addition, a 12-in.-diameter PVC pipe can be used. Some users have reported that a dark-colored interior in the pipe or bucket reduces glare.

sealer, although it is usually wise to also secure it with 3 or 4 bolts. In addition to helping spot shells and other items, it is useful to hold collected material. However, a bucket pushed close to the substrate in shallow, swiftly flowing water has a tendency to increase water velocity along the bottom. Frequently, WES workers have noted that shells or other items of interest were swept away when the bucket was lowered for a closer look. H. Mathiak reports that polaroid glasses are useful as a visual aid (Mathiak 1979).

Sampling With Divers

70. None of the previously described methods (except grab samplers) provide quantitative data on mussel densities. If an investigator wants reliable information on densities/sq m, usually a SCUBA or hardhat diver equipped with a quadrat must be employed. The quadrats can be constructed easily and cheaply from 3/4-in. PVC pipe (Figure 3-12, Table 3-10). WES personnel drilled holes in the PVC pipe to allow water to enter the pipe and avoid flotation. A 5-lb weight can be made easily and attached to the PVC line to help hold the quadrat on the bottom (Table 3-11).

71. SCUBA divers can cost from $200 to $300 per day; in addition, a diver often requires considerable time to reach the site, don equipment, and get to the mussel bed. If the bed is productive, a diver can use a tank of air obtaining a dozen 1-sq-m samples; if the water is cold or conditions not optimal, more time may be required. Unless time and money are not restricted, it is inefficient to use a diver to reconnaissance many sites and check for presence of mussels.

72. WES has had good success using divers to take quantitative samples from existing mussel beds. The diver used a quadrat which was set along a 50-m line marked randomly with small weights. The line was secured at both ends with a weight and a buoy. This work is done more by touch than by sight; for this reason a 1-sq-m or smaller quadrat works better than a larger size. Mussels were sent to the surface via a

3-gal bucket with two lines; one line was attached to the boat and the other line secured to the quadrat.

Handling Live Mussels

73. If live specimens are to be retained for study or identification, they can usually be held in a bucket for several hours before preservation techniques are required. A muscle relaxant is often added to the water at this time if specimens are to be preserved (see Part VII). It is important to carefully and properly replace mussels in the substrate in a nearly natural position if they are not to be retained; high mortality often occurs if specimens are simply tossed into unsuitable areas (Imlay 1972). This is easy to do if one remembers that the posterior part of the shell is the narrow end farthest from the umbones. The shell should be reburied so that only the posterior part, through which the animal siphons water for food and oxygen, projects above the bottom. When males and females can be distinguished, fertilization of the eggs can be enhanced by placing the males slighly upstream of the females. Although time and cost may not allow for proper handling of all the specimens, any uncommon or rare species should definitely be handled with care.

Field Notes

74. The importance of accurate field notes in any time of biological survey is often overlooked. Pertinent information concerning the location of the site, and characteristics of the habitat should be recorded for future reference. For more information on keeping accurate field notes see Clarke (1981); for material on all aspects of sampling see How to Collect and Study Shells (Jacobson 1974) and the sources listed in Table 8-3, Part VIII.

Discussion

75. WES's choice for reconnaissance-type work in deep water is a 5-ft brail constructed from a 2-by-4 and equipped with 18 chains with a total of 90 hooks. However, Bumgarner (1980) describes a 200-chain, 10-foot brail as "standard" for the Mississippi River. This larger brail, while slightly more difficult to use, will of course sample twice the area of a 5-ft brail. WES personnel have found that hooks constructed by them out of small-diameter (No. 26) stiff wire, when equipped with beads, will take specimens ranging from 3 to more than 17 cm in total length. The chains are attached to the bar with quick-release snaps.

76. WES samplers have found the dip net dredge fairly difficult to use, although it can capture more specimens than the brail when mussels are scarce or deeply buried. Starrett (1971) recognized that this was a time-consuming operation and felt that it missed some deeply buried organisms. The dip net dredge is not strictly an alternative to the brail or a SCUBA diver; it should be classed as a technique intermediate between both. The main problem with the dip net dredge is the difficulty of using it from a small boat, one solution to which would be pulling a modified mechanical dredge from a small boat.

77. For investigating shallow stream areas, personal preference probably is the most important consideration when choosing hand devices. The see-through bucket, because it provides service both as a container and to assist visibility, is one of the most useful items for mussel collecting. In general, the basket dredge works best in soft bottoms and is not effective in gravel or rocky areas; its construction requires experience with welding, but it is well worth the time if soft substrates are to be surveyed regularly. The rakes work well in mud, although they do not capture specimens as easily as the basket dredge; unlike the basket dredge, they function in sand and gravel substrate. The pitchfork is a good choice in rocky, swift areas because not only does it give support (and protection) to the investigator, but it also

can be used to pry loose rocks and dig into hard-packed gravel where the other devices are not effective.

78. Although unionids and Corbicula are taken with benthic grab samplers (Peterson, Ponar, Ekman, Shipeck), WES has found that these samplers are of limited use for most bivalves. When collecting mussels in deep water WES personnel use mainly a Petite Ponar for collecting substrate samples. Generally speaking, the grab samplers are time-consuming to operate and do not sample enough substrate to make their use worthwhile for most mussel surveys.

Table 3-1

Evaluation of Mussel Sampling Equipment and Methods

Device	Where Most Effective	Difficulty of Construction	Comments
Brail	Flowing water in shallow to deep streams and rivers	Fairly easy although time-consuming	Exploratory
Dip net	Flowing and slack waters with mud/sand/small gravel bottoms where depths are less than 10 ft	Fairly difficult	Exploratory; can damage shells
Grab samplers	Flowing and slack water habitats	Must be purchased	*Quantitative, although not* recommended for general mussel studies
Mechanical dredge	Flowing and slack waters at depths greater than 10 ft	Fairly difficult	Used for commercial purposes; can damage shells
Basket sampler	Shallow water (less than 1.0 metre) with mud and sand substrates	Fairly difficult	Highly recommended for soft substrates
Rake	Shallow water (less than 1 metre) with mud, sand, and gravel substrates	Easy	Fairly effective in mud and gravel
Pitchfork	Shallow water (less than 1 metre) with gravel and rock substrates	Easy	Very effective in gravel and rock as well as sand and mud
SCUBA	Shallow to deep waters of streams and lakes	Not applicable	The only truly *quantitative* way of collecting mussels in deep water; however, very expensive and time-consuming

Table 3-2

Materials and Costs for Reversing Pliers Construction

Quantity	Unit	Material	Price	Unit Total
1	ea	Snap-ring pliers with removable points	9.95	$ 9.95
1	piece	3/4- x 1/2- x 1/16-in. elliptical-shaped steel rod	0.50	0.50
			TOTAL	$10.45

(Requires 1/2 manhour to construct)

Table 3-3

Materials and Costs for Brail Bar Construction

Quantity	Unit	Material	Price	Total
1	ea	3-1/2- x 1-1/2- x 10-ft hard-wood board	9.30	$ 9.30
40	ea	Screws eyes, 1-3/4 in.	0.13	5.20
40	ea	"S" hooks, 1-1/2 in.	0.10	4.00
60	ft	Galvanized chain 2/0	0.22	13.20
200	ea	"S" hooks, 1-3/4 in.	0.06	12.00
200	ea	Brail hooks	0.22*	44.00*
3	ea	Zinc-plated eye bolts w/nuts, 3/8 x 6 in., No. 6B	0.58	1.74
1	ea	Steel round ring, No. 2 x 2 in.	0.45	0.45
1	ea	Snap, large	3.50	3.50
75	ft	1/2-in. twisted 100% nylon rope	0.33	24.75
40	ea	Snaps, 1/4-in., No. 334	0.48	19.20
1	ea	Handle, 6-1/2- x 1-3/4- x 1-1/2-in. in length	1.25*	1.25*
			TOTAL	$138.59

(Requires 8-10 manhours (if hooks are available) to construct)

* Cost of materials only.

Table 3-4

Materials and Costs for Brail Hook Construction

Quantity	Unit	Material	Unit Price	Total
600	ft	Music wire, #26 diameter*	0.07	$42.00
250	ft	Wire, galvanized fence, 17 gauge*	0.02	5.00
			TOTAL	$47.00

(Requires 6 manminutes per hook; 40-60 manhours for 220 hooks)

* For approx. 220 brail hooks.

Table 3-5

Materials and Costs for Dip Net Dredge Construction

Quantity	Unit	Material	Unit Price	Total
1	ea	1-in. x 2-in. x 15-ft aluminum flat bar	5.80/ft	$ 87.00
		or		or
1	ea	1-in. x 2-in. x 15-ft rectangular tubing with 0.083-in. wall thickness	0.75/ft	11.25
1	ea	1/4- x 2- x 75-in. flat steel bar	1.00/ft	7.00
2	ea	1/4- x 4- x 6-in. flat steel bar	1.50/ea	3.00
1	ea	1/2- x 44-in. round steel rod	1.60	1.60
1	ea	60- x 36-in. netting, with 1/2- to 1-in. mesh	2.50/ft	7.50
2	ea	1/2- x 2-1/2-in. hex head bolts	0.45	0.90
4	ea	1/2- x 2-in. hex head bolts	0.40	1.60
6	ea	1/2-in. hex nuts	0.20	1.20
6	ea	1/2-in. lock washers	0.10	.60
2	ea	2-1/2-in. round rings	0.50	1.00
			TOTAL	$111.40
				or
	(Requires 20 manhours to construct)			$ 26.55

Table 3-6

Materials Required to Construct The American Version of the Basket Dredge

Material	Quantity
Iron bar for frame, 0.5 cm in diameter	2.3 m
Rods for base of basket, 0.3 cm in diameter	50 rods, 35 cm long
Hardware cloth, 1-cm mesh	1 piece, 91 x 13 cm
Wooden pole	1 piece, 1.2 m long
No. 20 wire to secure hardware cloth to frame	1.5 m
(Requires 6 manhours to construct)	

Table 3-7

Materials and Costs for Mussel Rake Construction

Quantity	Unit	Material	Unit Price	Total
1	ea	Garden rake	16.00	$16.00
4	ft	1/4-in.-mesh hardware cloth, 36 x 48 in.*	2.00	8.00
4	ft	Small-mesh netting, 36 x 48 in.	2.50	10.00
1	roll	Nylon string	1.15	1.15
			TOTAL	$35.15

(Requires 4-6 manhours to construct)

* Either 1/4-or 1/2-in.-mesh net or hardware cloth can be used.

Table 3-8

Materials and Costs for the Pitchfork Sampler Construction

Quantity	Unit	Material	Unit Price	Total
1	ea	Pitchfork, 3-prong	22.00	$22.00
		or		or
1	ea	Pitchfork, 4-prong	23.00	23.00
1	piece	1/4- or 1/2-in.-mesh hardware cloth, 12 x 12 in.	1.00	1.00
2	ft	No. 17 fence wire	0.30	0.60
				$23.60
				or
				24.60

(Requires 1 manhour to construct)

Table 3-9

Materials and Costs for See-Through Bucket Construction

Quantity	Unit	Material	Unit Price	Total
1	ea	Bucket (plastic)	1.00	$ 1.00
1	piece	Plexiglass, one sheet	5.00	5.00
1	tube	Silicone adhesive, RTV-108	5.10	5.10
				$11.10

(Requires 1 manhour to construct)

Table 3-10

Materials and Costs for Quadrat Construction

Quantity	Unit	Materials	Unit Price	Total
4	ea	PVC elbows, 3/4 in.	0.23	$0.92
13	ft	PVC pipe, heavy-wall, 3/4 in.	0.14	1.82
1	1/2 pt	Glue, PVC	1.85	1.85
2	ea	PVC couplings, 3/4 in.*	0.16	0.32
2	ea	Stove bolts, 1/4 x 1 in.*	0.15	0.30
2	ea	Wing nuts, 1/4 in.*	0.10	0.20
4	ea	Eye bolts w/nuts, 1/4 in.** x 6 in.	0.34	1.36
2	ea	3/4-in. unions, galvanized*	1.69	3.38
2	ea	3/4-in. PVC threaded nipples*	0.23	0.46
			TOTAL	$6.77
				or
				$9.79

(Requires 1 manhour to construct)

* Optional; makes breakdown of quadrat possible (either coupling and bolt or union and nipple can be used for breakdown of quadrat).

** Optional; can be used to attach weights and to stick into substrate.

Table 3-11

Materials and Costs for Clip-on Weight Construction

Quantity	Unit	Materials for 5-lb wts	Unit Price	Total
20	lbs	Lead	1.50 lb	$30.00
4	ea	1-3/4-in. screw eyes	0.13	0.52
4	ea	1-1/2-in. "S" hooks	0.10	0.40
4	ea	1/4-in. Snaps, No. 334	0.48	1.92
			TOTAL	$32.84

(Requires 1/2 manhour to construct)

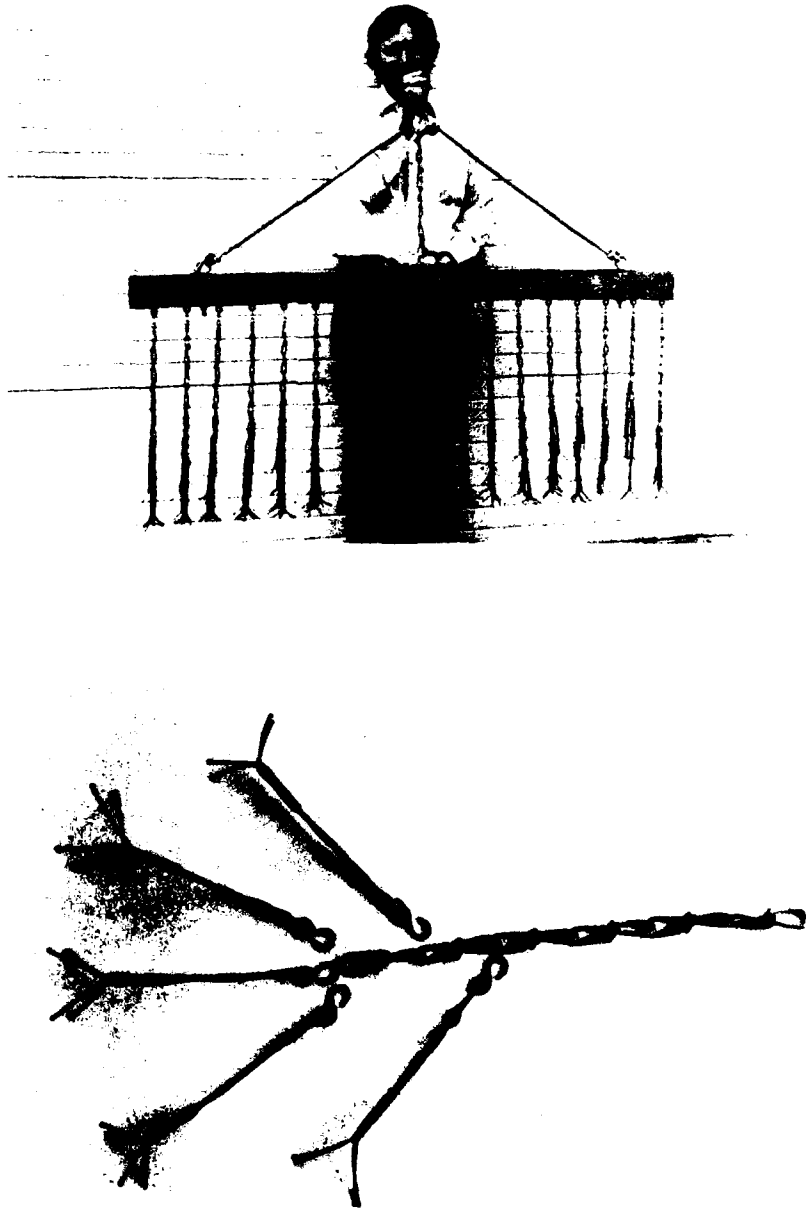
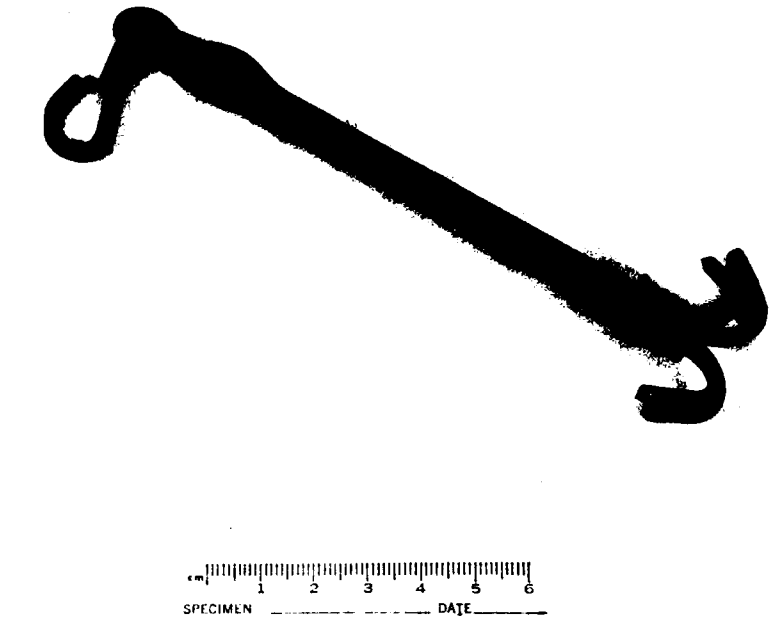


Figure 3-1. A 5-ft wood brail and hooks constructed at WES; detail of hooks and chain.



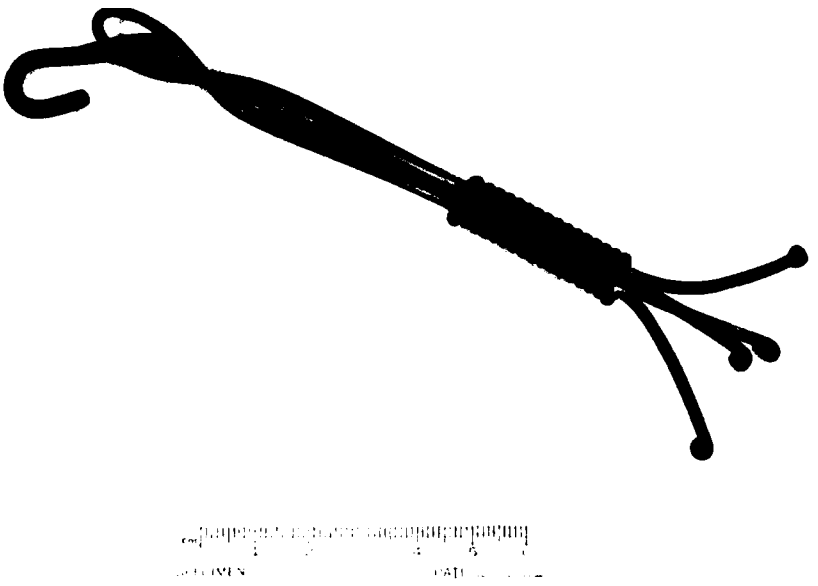


Figure 3-2. Detail of commercially made mud (above) and rock or dovetail hook

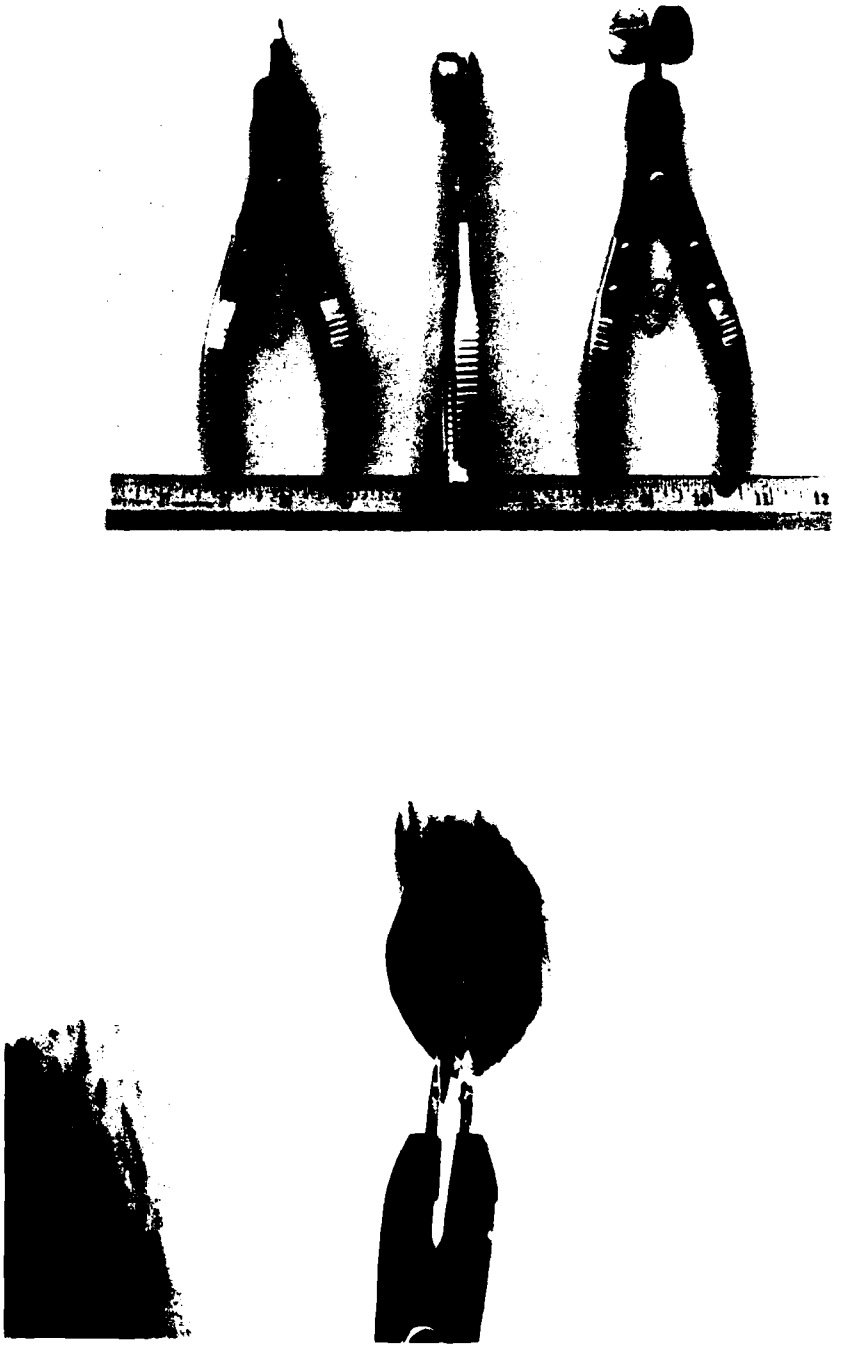


Figure 3-3. Views of reversing pliers for opening valves of mussels

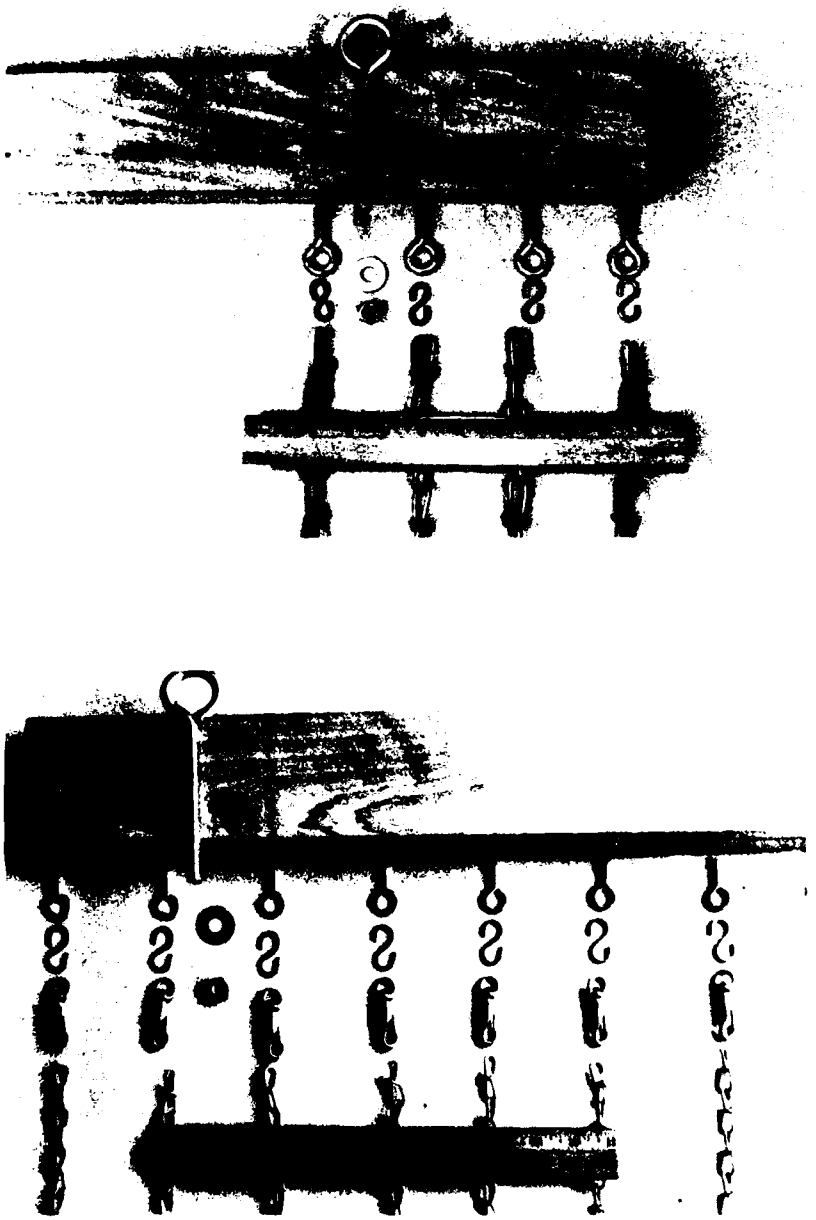
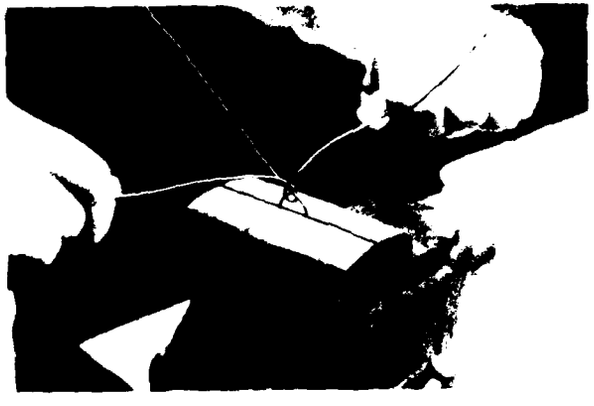


Figure 3-4. Detail of hardware for brail construction without (above) and with quick-release snap clips

a.

b.



c.

Figure 3-5. Constructing brail hooks: First a loop is placed in a 16-in. piece of No. 26 music wire (a); next, a second wire of equal length is threaded through the loop (b) and pulled tight (c); (continued)

d.

e.

f.

Figure 3-5. (Continued) third, the wires are pulled together, placed back into the vise, and held by their tips for twisting (d); fourth, soft wire is wrapped around the stiff wires (e). After the ends have been trimmed (f), a bead should be placed on the end of each wire

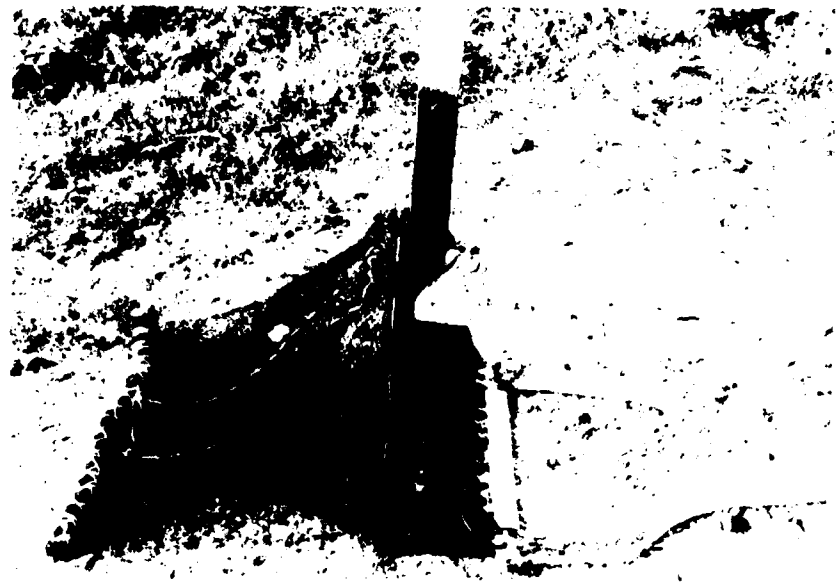
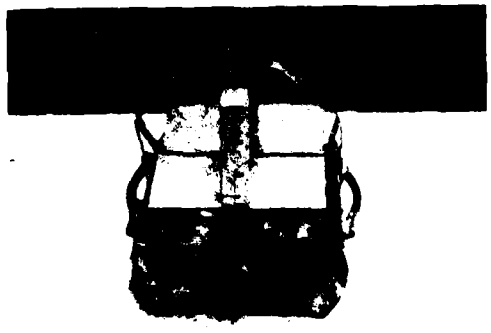
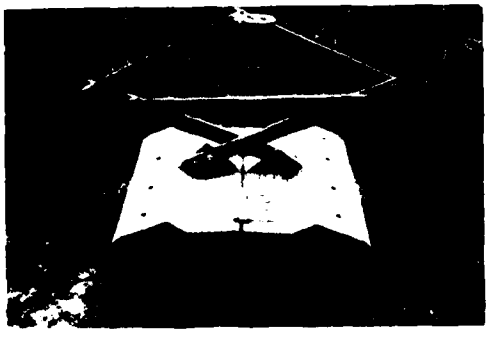


Figure 3-6. Completed dip net (upper); preparing to use the dip net in the upper Mississippi River (the dip net was constructed and operated by personnel from the U. S. Army Engineer District, St. Paul)

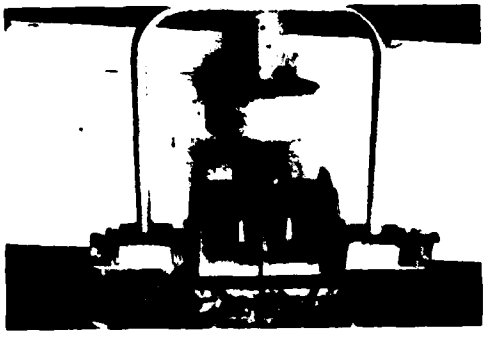


a.

b.



c.



d.

Figure 3-7. Grab samplers: (a) Ekman, (b) Ponar, (c) Peterson, and (d) Shipek

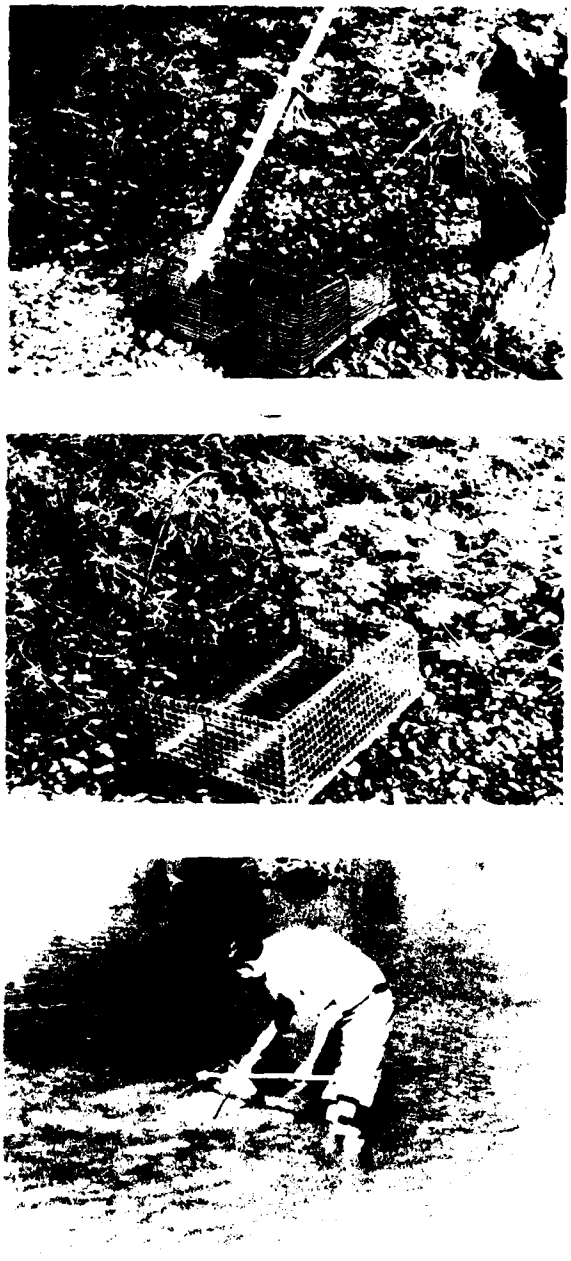
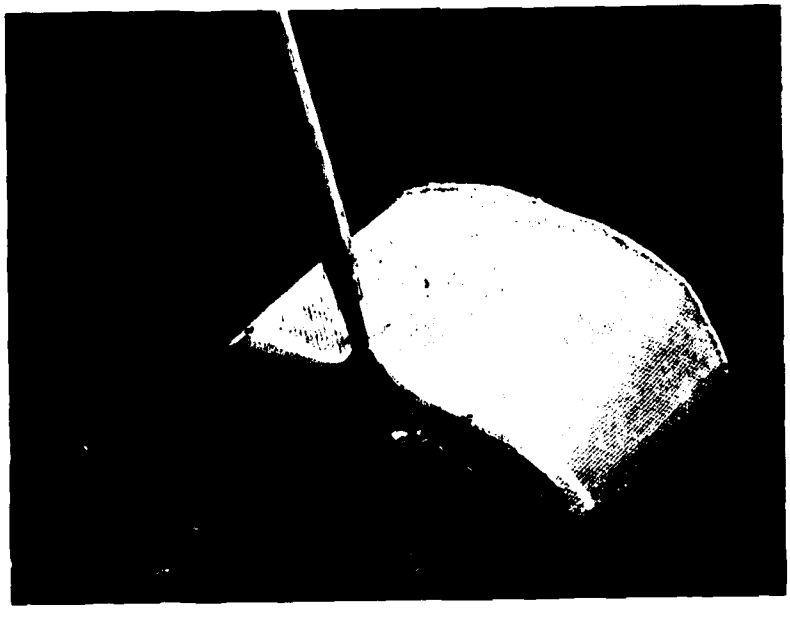


Figure 3-8. Taiwanese basket dredge (top) constructed from various sizes of wire; an American version (center) constructed by welding steel rods to an iron frame and wrapping the back and sides with hardware cloth; the dredge in action.



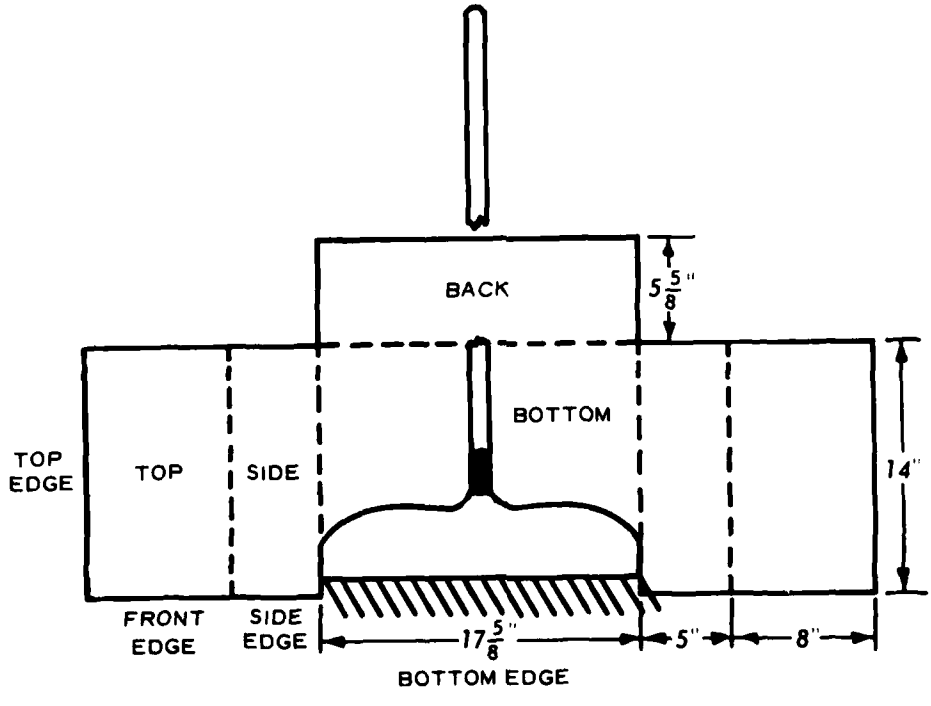


Figure 3-9. A garden rake modified with hardware cloth

Figure 3-10. A pitchfork modified with hardware cloth can be used to collect mussels in rocky areas

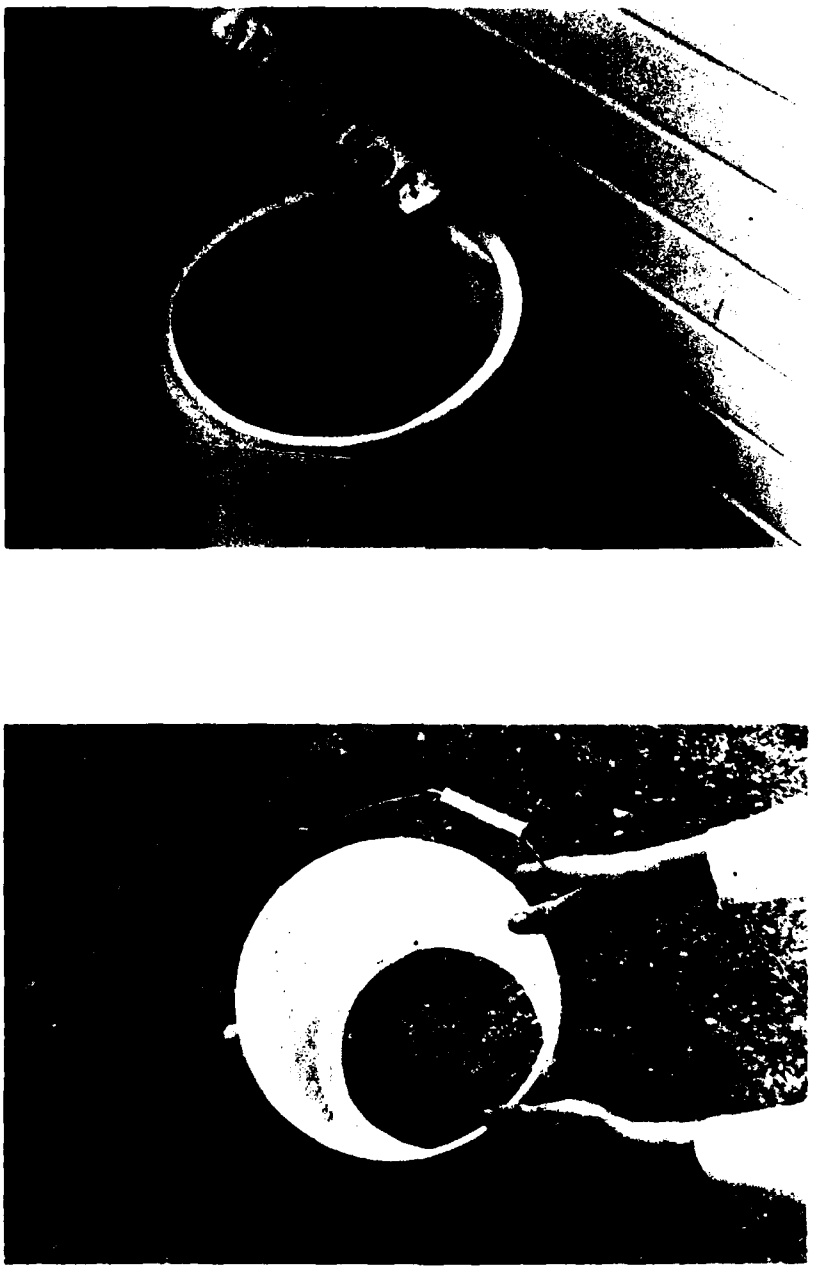


Figure 3-11. The see-through bucket can be constructed easily with plexiglas and silicone sealer and is useful for spotting and transporting shells

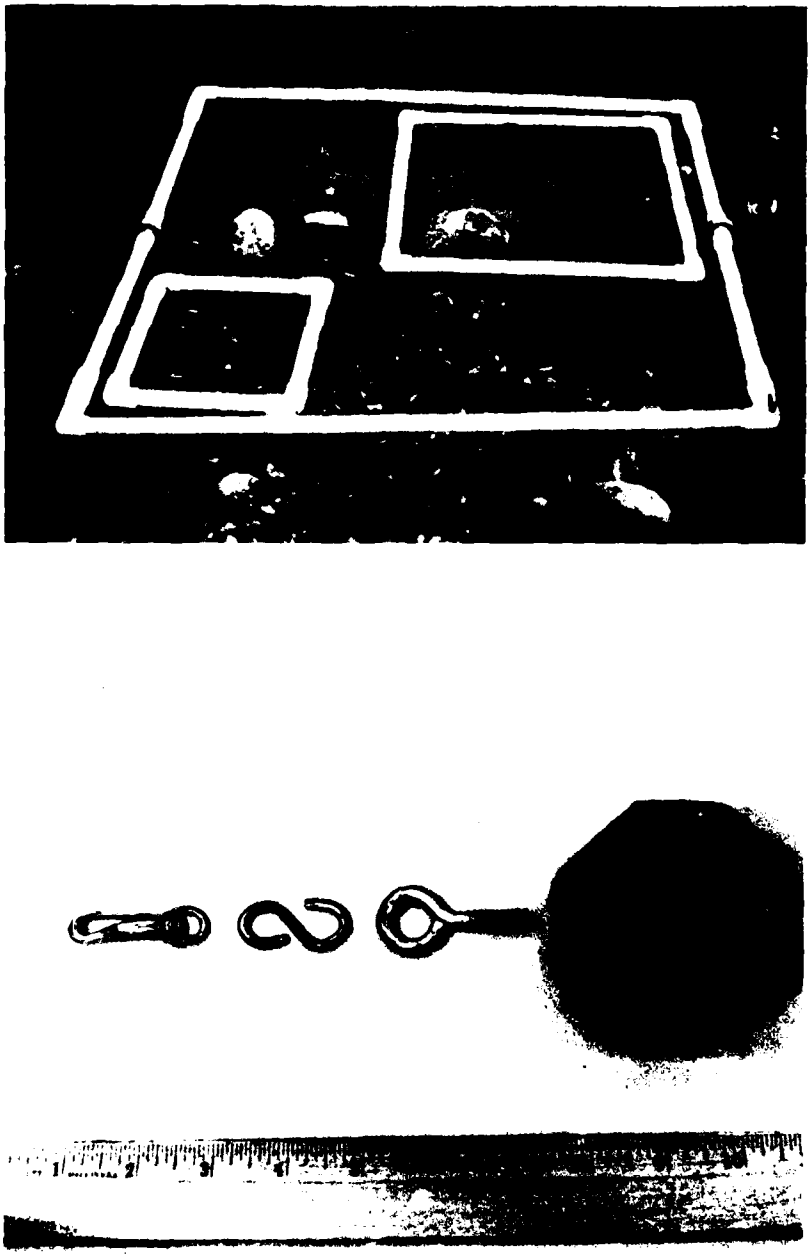


Figure 3-12. Quadrats (0.0625, 0.25, and 1.0 sq m) are easily constructed from 3/4-inch PVC line. A 5-lb weight can be used to secure a quadrat, or to hold down a brail bar

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PART IV: EFFICIENCY OF SELECTED SAMPLING TECHNIQUES

Introduction

78. As described in Part III, the only truly quantitative sampling method for mussels is the use of a quadrat sampler. This device can be used by hand in shallow water or operated by a diver equipped with either SCUBA or snorkel apparatus in fairly deep water. It is the purpose of this section to present data on the efficiency of other mussel-sampling techniques. Knowledge of the limitations and success of these other techniques will assist the investigator in judging the reliability of collected data.

Limitations of the Brail

79. In November 1981, WES tested a 5-ft brail bar equipped with 90 hooks, constructed at WES (see Part III). The tests were conducted in the Ouachita River, Monroe, Louisiana, in water about 3 m deep. The substrate consisted mainly of soft mud with little or no sand or gravel present. The Ouachita River is maintained for navigation by the U. S. Army Corps of Engineers; velocities range from 1 to 3 mph, and depths up to 30 ft. At the study point the river was about 700 ft wide.

80. The brail was worked in areas where total mollusk densities ranged from 0 to over 100 individuals/sq m (see Table 4-1). There was a total of 7 species in the mussel bed, including the Asian clam Corbicula. Average densities of unionids in the three transects ranged from 1 to 6 per sq m; Corbicula ranged from 7 to 96/sq m. As a result of operating the brail in the three transects, only a single Corbicula was captured; this specimen was obtained on the third transect. The diver observed that the mussels were not buried very deeply in the substrate and should have been taken by the hooks; however, the water temperature was measured at 55°F, and most of the mussels appeared to be closed at the time the test was conducted.

81. However, in the spring of 1982 WES brailed (using a 5-ft bar) a known mussel bed in the Big Black River near Bovina, Mississippi. In this bed there were 17 taxa, and the average density was 94.3 bivalves (0.7 Corbicula) per sq m. A single 25-m pull through the bed yielded 23 individuals and five different species. While the bed contained roughly the same number of bivalves per sq m, the substrate in the latter area was extremely hard-packed; it was difficult to dig specimens out of the bottom by hand. However, when the sampling was done in the Big Black River, water temperatures were 72°F; obviously mussels were open and filtering, making them more susceptible to being caught by the brail.

82. Table 4-2 compares the WES data with the results of three brail efficiency tests conducted by other workers. No reported survey shows efficiency greater that 4.0 percent. In no survey did the brail collect all species present, although in the work done by Thiel et al., 26 out of 27 species present in a mussel bed were collected using the brail.

83. Poor efficiency with the brail can be attributed to the following:

a. Decreased water temperatures.

b. Mussels buried too deeply in the substrate.

c. Organisms not properly oriented.

d. Valves not opened properly at time of collection.

e. Hooks missing the mussel or not irritating the tissue enough to cause closure.

f. Incorrect brail construction or operation.

84. When a hook slides between the valves (at room temperature), it takes about a second or more for the valves to completely close.* Once the valves have clamped shut the hook is firmly held and there is little chance that the organism will fall off; WES has observed one individual remaining on a hook for 4 hours. The organism can slide off an unbeaded hook if the wire is of small diameter (about #26); however,

* Observations conducted in the laboratory at WES.

mussels will hold to a larger gage wire (#12 or larger) even without a bead. Mussels will not hold to an unbeaded hook of large diameter as well as to a beaded hook; in addition, there is a chance for mussels to be pulled off unbeaded hooks much more easily than off beaded hooks. It is also important to remember that if a large-diameter (#12 wire) is beaded, the resulting hook will be so large that small species and individuals cannot be captured.

85. Many workers have recommended using a variety of wire sizes for hooks to ensure catching a diversity of sizes of mussels. Using #26 wire, WES has taken small Corbicula (3 to 4 cm) and fairly small unionids (about 5 to 6 cm). These hooks take large specimens, although a large M. gigantea could be missed if its valves did not close properly on narrow wire. There is no doubt that a variety of wire sizes on the same brail should be used to maximize the diversity of catch.

86. Another feature which increases the usefulness of a brail bar is the addition of short lengths (about 4 in.) of monofilament line to the hooks. One end of each line should be secured to the hook, the other end is knotted and allowed to hang free. The monofilament line will catch very small mussels (less than 1.0 cm) by their byssal threads.

87. The role of chance in catching mussels with a brail is impressive. A hook must slide properly between the narrowly opened valves of a properly oriented individual. The hook must penetrate deeply enough into the viscera to cause the animal to close. The boat must be moving slowly enough so that the hook is caught by the valves before it is pulled away from the shells.

88. Table 4-3 contains a list of mussels that have been captured using a brail. Certain species in the genus Quadrula, also M. gigantea and certain Pleurobema, are more likely to be taken with the brail than are the thin-shelled species which often bury deeply into the substrate (Anodonta). In addition, the spectacle case (Cumberlandia mondonta), which can be found in cracks between large rocks, is often not taken with the brail. Finally, it must be remembered that the brail is

neither quantitative nor qualitative* and is best used as a reconnaissance or exploratory device.

The Efficiency of Other Mussel-Sampling Equipment

The bucket viewer

89. We have not found the bucket viewer to be very effective when the turbidity of the water is much greater than 30 Jackson Turbidity Units (JTU). If the viewer is to be used from a boat with any degree of effectiveness, turbidity will have to be less than 5 or 10 JTU. The viewer will increase the velocity of moving water around and beneath it. If the bucket is pushed down towards the bottom, the increased water velocity will often sweep away small mussels or snails before they can be retrieved.

Garden rake

90. We have found the garden rake with flexible mesh netting less cumbersome and easier to use than one built with rigid hardware cloth (see Part III). The garden rake is probably best employed in sand or sand-gravel mixtures. When using the rake do not expect that a single pass through a bed will remove all specimens. Often the rake has to be vigorously and repeatedly pulled through an area before enough gravel is moved to get at the mussels. It is not uncommon to get the tines of the rake wedged in between the valves of a large mussel, although most specimens are retrieved from the screen or netting.

Pitchfork

91. The modified pitchfork is best used in an area where there are large rocks and riprap, although it can be used effectively in soft substrates. It can be used to pry apart and lift rocks and is a good exploratory device. The pitchfork is not of as much use in sand or mud as the other rakes or the basket sampler (discussed below). The screen

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* Personal communication, 1981, Dr. Arthur Clarke, Malacologist, ECOSEARCH, Mattapoisett, Mass.

helps to hold mussels, although shells often fall off when the collector is digging about in the water.

Basket dredge

92. We have found the basket dredge to be the most effective device to use by hand in mud or light sand substrate. If large rocks, twigs, sticks, or aquatic plants are present, the tines bend and the basket operates inefficiently. The basket dredge actually digs into the substrate so it can often retrieve all mussels in a single pass, unlike the previously mentioned rakes and pitchfork. The pitchfork and the rake can be used to probe and dig in an area; the basket dredge is used to pull through or sweep a section of bottom. If there is a need to obtain large numbers of mussels from sandy or soft substrate, the basket dredge should be the apparatus used.

Quadrats

93. In a series of tests WES compared a diver's use of three sizes of quadrats (1.0, 0.25, and 0.0625 sq m). The test was conducted in the Ouachita River, Louisiana, where Corbicula densities were high and the substrate consisted of soft mud. The ratio of large organisms (Plectomerus dombeyana) to small (Corbicula, Toxolasma sp.) collected with each size of quadrat was about the same, which indicated that the diver was retrieving various specimens equally well regardless of quadrat size. Although the diver did not know we were conducting a test, he performed a thorough collection. Typically, he sent a large quantity of sediment to the surface at each site; obviously he was not truly searching for mussels but was retrieving everything which remotely resembled a mussel (which included snails, bits of shells, and occasionally stones and old tools) to the surface.

94. If the mussel bed is diverse and contains 100 or more organisms per square metre, it makes sense to use a smaller quadrat (0.25 sq m). The 0.0625-sq m quadrat works well but takes very small samples. If mussels are very scarce, this small-size quadrat may not capture any; if the mussels are quite large (like giant washboards), often only parts of the organism will be within the confines of the quadrat after it has been placed. Although the investigator is better

off to collect a large number of small-size samples (rather than the reverse), there is no doubt that the larger quadrat will more quickly reveal unusual specimens than an equal number of small quadrat samples (see Part V). In our experiment a 1.0-sq m quadrat is about the largest size a diver can easily cover. One man can easily reach across a 1-m quadrat and not miss any areas.

Diver

95. A diver can cost from $200 to $300 per day, and he can operate poorly or not at all in large, turbulent waters, in dangerous areas near dams, or when the water is cold and rough. WES has found that a diver can sample about dozen 1-sq m quadrats with a single tank of air in fairly shallow water. At this rate, the diver may sample no more than 20 or 30 1-sq m quadrats per day.

96. There are also many logistic problems associated with use of a diver; it is easy to overestimate the amount of work that can be done with SCUBA. There is the need for air, boats, motors, gasoline, functional equipment, and support personnel to assist the diver. Common sense dictates that at least two divers should be available in case of accidents or unforeseen problems. In general, a diver should be used for a specific task such as checking the efficiency of a sampling device, making quantitative samples along a transect, or transplanting mussels from one area to another. General reconnaissance work should be left to the use of brails, dredges, dip nets, or surveys in shallow water.

97. In WES's experience it is best to have a diver work with a quadrat sampler or follow a transect and retrieve all specimens within arm's length or within a particular length of line. When a diver is sent down simply to collect all he encounters in a general area, he usually misses organisms and is not very efficient. Under these situations there is a tendency for the diver to move about aimlessly and to pick up and search for old tools, bottles, and other things of interest. WES has had good success with divers who were not trained scientists. Typically, they are knowledgable about mussels, often know where mussels are found, and like to see them protected. Because of their experience

in working underwater, they rapidly learn to separate the various taxa by feel.

Table 4-1

Average Densities* (per sq m) of Mollusks in Three Transects on the Ouachita River, November 1981

	Transect Number		
	1	2	3
Unionid mollusks	5	1	6
Corbicula	78	7	96**
Total bivalves	83	8	102
Total mollusk species	5	3	7

* Based upon collections by a diver equipped with SCUBA.

** One Corbicula was taken by brail.

Table 4-2

Efficiency of the Brail Based on Tests of Four Collectors

	Species Present	Species Captured	Efficiency*
Scrugge (1960)	16	11	0.36
Thiel et al. (1980)	27	26	0.14-2.5
Krumholz et al. (1970)	10	3	3.6
WES (described in this report)	8	1	0.1

* Efficiency is based upon a comparison between numbers of individuals of all species present and numbers actually taken with the brail.

Table 4-3

Mussels Taken Using a Brail During Various Surveys (From Scrugge 1960, Krumholz et al. 1970, Kraemer and Gordon 1980)

Fusconaia ebena	Actinonaias carinata
Megalonaias gigantea	Obovaria subrotunda
Amblema plicata	Proptera alata
Quadrula pustulosa	Elliptio crassidens
Quadrula nodulata	Fusconaia undata
Quadrula cylindrica	Quadrula metanevra
Quadrula quadrula	Alasmidonta marginata
Tritogonia verrucosa	Anodonta grandis
Plectomerus dombeyanus	Anodontoides ferussacianus
Elliptio dilatatus	Lasmigona compressa
Anodonta grandis	Strophitus rugosus
Obliquaria reflexa	Cyprogenia irrorata
Obovaria olivaria	Leptodea laevissima
Truncilla truncata	Cyclonaias tuberculata
Leptodea fragilis	Plethobasus cyphyus
Lampsilis anodontoides	Pleurobema cordatum
Lampsilis ovata ventricosa	Plagiola lineolata
Lasmigona complanata	Truncilla donaciformis
Lasmigona costata	Lampsilis higginsi
Corbicula	

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PART V: DESIGN OF A SAMPLING PROGRAM

Introduction

98. It is the intent of this section to provide information necessary to plan an efficient program for sampling mussels. Too often there is a tendency to charge into the field, collect as much data as possible, then attempt to rely on a computer to find out "what it all means" (see Green 1979). Many times Environmental Impact Statements are filled with meaningless lists of species collected or observed at a site and contain little or no interpretation of the information. Because of the difficulties of collecting and identifying certain genera, there is often more emphasis on obtaining and identifying shells, resulting in many mussel studies that are more cursory than ecological. The following material on planning a sampling program for mussels is based upon WES experiences plus the results of various quantitative mussel studies (Scruggs 1960, Krumholtz et al. 1970, and Green 1979).

Types of Surveys

99. It is important to determine exactly the objective of the investigation before detailed survey planning is put into effect. This section describes three types of surveys, which probably cover the majority of the work to be conducted by Federal biologists when investigating an area for freshwater mussels.

Preliminary reconnaissance survey

100. The primary objective of this type of survey is to gather general information on the study site. Depending on the outcome of this work, a full-fledged survey (or perhaps no survey at all) might then be in order.

101. Before going into the field it is important to obtain as much data as possible on water depths, discharge, velocity, substrate types, location of effluents, and water levels for the study area. The U. S. Geological Survey, Soil Conservation Service, U. S. Fish and

Wildlife Service, and many other State and Federal agencies either collect or have these types of data available. In addition topographic maps are a necessity, while aerial photographs (1:12,000 black and white stereo pairs) should be obtained if detailed work is planned for a later time.

102. After obtaining all available background data, the investigator should perform a preliminary or cursory field investigation. When visiting the site, take a rake (or other appropriate tool, see Part III) and investigate as many shallow areas as possible. If a small boat is available, this can be used for investigating shallow water using hand equipment or bucket viewers. Often, wading along shore while carefully feeling about by hand in soft substrate is the most successful method. In addition, shells are often seen at the water's edge or some distance up on a bank or in trees and brush. The following are places where WES has found living and dead mussels:

a. In shallow pools adjacent to streams and rivers.

b. On exposed gravel bars of large and small rivers.

c. In isolated pools and farm ponds.

d. In soft sediment adjacent to beds of vegetation.

e. Along brush piles on riverbanks where trash is left by high water.

f. Buried several inches under gravel in shallow water.

g. In the stomachs of large catfish, freshwater drum, and aquatic turtles.

h. At times of low water in bayous, canals, creeks, and marshes.

i. In large rivers below the mouths of tributary streams.

j. Directly below small dams on fairly large rivers (the exception to this are hypolimnetic releases from very large reservoirs).

k. Dredge material areas.

l. Below dams that are temporarily closed for maintenance. (The U. S. Army Engineer District, Nashville, collected mussels and other benthos during a zero discharge period in the Cumberland River below Wolf Creek Dam, Kentucky. With flows stopped for three days, workers were able to get into dewatered areas and collect shells and some live mollusks by hand.)

103. Periods of low water are the preferred times for collecting mussels, although it is not always possible to survey at these times. However, the investigator should collect as many shells as possible during this first survey; many times after specimens are returned to the laboratory for proper cleaning and examination it is apparent that there are more species inhabiting the site than was previously thought. If a bed of live mussels is encountered, it is important to make an adequate representative collection but not destroy the resource. When live mussels are returned to water they should be inserted into the substrate carefully (see Part III, paragraph 76).

Qualitative survey

104. If the shoreline-shallow water survey yields positive results and there is a lot of deep water in the area that was not sampled, it is advisable to further investigate the site using a brail, dipnet dredge, or mechanical dredge (see Part III). WES prefers a 5-ft brail bar for rivers since it is lightweight, easy to use, and does not require as many hooks as a larger 10- or 12-ft bar. However, it is important to note that using the smaller brail cuts the potential sample in half. This can be compensated for by more or longer tows. Both the dipnet and mechanical dredges are difficult to construct and use, although they can operate fairly efficiently in slack water where a brail is not usable. As described in Part IV, all of these devices are qualitative to a certain extent and can miss certain species. Although WES has used both the dipnet and mechanical dredge, the brail is preferred for its ease of operation and construction.

105. When using a brail it is important to record either the distance traveled or the time spent on a specific transect. A reference to distance (using landmarks along the shore and maps or aerial photographs) is preferred for accuracy since timing the tow usually does not give an accurate estimate of distance covered. However, a 10-minute tow at 2 mph will cover 1760 ft (about 600 yards) and is usually sufficient for most surveys. Make a series of transects parallel to the shore, working from shallow to deep water. Always brail with the current, since mussels orient themselves with the flow. It is important to be

prepared for disappointments when using a brail. Although professional clammers sometimes catch so many mussels that the bar can barely be retrieved from the water, the scientific investigator does not always have the chance of collecting in areas where specimens occur. WES has brailed many times when less than half of the tows yielded live mussels. For more information on efficiency of the brail and other devices see Part IV.

106. The objective of a qualitative survey is to gather background data on mussels and decide if more detailed studies are required. Probably the most important consideration is to ascertain whether or not the species in question has any likelihood of being found in the area. A field guide to endangered mussels (Clarke and Fuller 1983), which includes information on the range, reported habitat preferences, and identifying characteristics, is available (from WES) and will provide assistance. However, because an area is reported out of the range of a particular species does not necessarily mean that a search should not be made. Many times certain species turn out to be more common than once believed after intensive surveys have been made; for example, the Higgins' eye mussel (Havlik 1981, Havlik and Marking 1980) in the upper Mississippi River and the Indiana bat in Kentucky and Indiana (Cope et al. 1974) are cases in point.

Quantitative survey

107. If a diverse mussel bed is identified by any of the previously described techniques (brail, dipnet dredge, shallow water or shoreline survey) and if the area under study is within the range of a federally listed species, a more detailed survey may be required. While background ecological data (see below) will enhance the study, it must be remembered that the major objective of this work is to ascertain the presence or absence of a particular species. In deep water the most efficient way to collect mussels is to establish a transect through the study area by laying a weighted line with a buoy and heavy weight (cement block) at each end. A diver equipped with SCUBA can move along the line searching for all mussels within reach. Mussels which approximate the species of concern by shape and size should be retrieved and

sent to the surface. Even though the diver may not know how to identify mussels, he can probably still recognize certain shapes very easily. On the surface, in a boat or on the shore, the specimens should be washed and examined more carefully. Mussels which are not immediately identifiable, or that are uncommon, should be retained. While using a diver following a transect is not strictly a quantitative technique, estimates can be made of the species composition per unit area by this method. Simply multipy the total length by the approximate area the diver can reach (i.e., the width) to obtain the total area. In a survey WES conducted on the Ouachita River, the diver obtained mussels on both sides of the line for a distance of about 2 m. The total area covered was 50 m by 4 m, or 200 m. If 50 individuals were collected, the density would be approximately 0.25/sq m. This procedure can be improved by having a diver collect all mussels within a sq m or 0.25-sq m quadrat (see Part III). However, while this provides quantitative data on species composition, it is time-consuming. Unless there is a specific reason why quantitative data is required, a single diver working a transect can provide semiquantitative results much more quickly than he can using a quadrat. The primary objective of this type of survey is to provide presence-absence data about a particular species or group of species.

108. In shallow water the investigator can use suitable handheld devices (rakes, etc.) or search by hand an area delineated by stakes or other landmarks. It may be possible to retrieve all specimens of interest simply by touch. If endangered or uncommon species are found, an estimate of the number per square metre can be determined from the number sampled and the total area of the study site calculated.

Ecological survey

109. An indepth ecological study should be conducted to collect information on the extant mussel population and appropriate physicochemical variables. This type of information will be useful for impact analysis and habitat evaluation. The major emphasis of this type of

survey is to identify existing mussels and relate their presence to existing conditions of habitat.

110. Initially, it is important to gather pertinent physical and chemical data on the area under study. This can be obtained on site, from the technical literature, or from existing data made available by the U. S. Geological Survey or the U. S. Environmental Protection Agency. A well-designed study will probably make use of information gleaned from all three of the above sources. Table 5-1 contains a list of appropriate variables which should be measured in an ecological or habitat study for mussels.

111. In a thorough ecological study, the investigator should endeavor to collect quantitative data on existing mussels. This is best done with an appropriate-size quadrat (see Part III) placed randomly in the mussel bed. WES feels that it is important to gather quantitative information to perform a detailed analysis of the mussel bed; this will be more than a simple species list or an indication of whether or not one or more species were present.

112. In the laboratory all specimens from each sample should be weighed to the nearest gram. Using a micrometer, record total length, height, and thickness of the total organism.* If facilities are available, choose at least three each of the most abundant taxa and obtain a dry weight after holding for 24 hr at 105°C. Each specimen should then be ashed at 550°C in a muffle furnace to determine percentage of organic matter in both the shell and viscera.

113. Two mussel beds, one in the Ouachita River in Monroe, Louisiana, the other in the Big Black River, Mississippi, were studied using quantitative techniques. In the Ouachita River a diver collected from 15 randomly placed 1-m quadrats in a 50-m transect. In the Big Black River, 12 0.25-sq m samples were collected by hand in water ranging from 45 to 60 cm in depth. The Big Black River mussel bed supported 17 taxa of mussels; the Ouachita had 6 taxa (Table 5-2). In the latter

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* These are "maximum" measurements. Gradually close the micrometer until the longest portion of the shell begins to scrape on the device.

bed, Corbicula dominated numerically, while the bank climber, Plectomerus dombeyana, was fairly common in both areas. However, this species was about five times as abundant in the Big Black River, and each organism (although roughly the same age) was about 5 times the weight of the Ouachita River individuals. The sediments in the Ouachita River were mud, while those in the Big Black River were mud with gravel and sand. Finally, the shells taken from the Big Black River were deeply eroded. This was probably the results of the increased abrasion caused by high flows and movement of sand and gravel and resultant increased corrosion from low-water hardness in the Big Black River.

114. Quantitative information provides much more data about the health, diversity, and ecology of a mussel bed than a few qualitative samples. For example, in the case of the previously described studies it is clear that the Ouachita River bed is stressed, the diversity is low, and specimens are stunted in size. The Ouachita River has a mud bottom with low flow, while the Big Black is a smaller river with much faster currents and a substrate consisting mainly of sand and gravel.

How Many Samples?

115. In a field study, one of the most important questions which needs to be answered concerns the number of quantitative samples it is necessary to collect. The major concern is to collect enough samples so that the investigator can make an estimate, within certain limits, of the true number of organisms (or of a particular species) in the population. Since under most conditions it is difficult, undesirable, impossible, or too expensive to sample the entire population, only a portion or a small sample can be obtained. The question of number of samples actually relates to two problems: (a) the variability of results in each sample and (b) the degree of precision required.

116. The question of sample number is treated by Green (1979), Elliot (1977), and Snedecor and Cochran (1967). WES has experimented with the problem of determining number of samples with the aid of a computer program which simulates a distribution of organisms in a 2-by-2

array. The user can predetermine which type of distribution pattern (random, cluster, uniform, see Figure 5-1) that he desires to simulate. After the community has been created and stored, a second program randomly collects a specific number of samples from the population. The following discussion is based on sampling computer-simulated populations, field studies conducted in Mississippi and Louisiana, and discussions in Green (1979) and Snedecor and Cochran (1967).

117. In a survey for mussels, quantitative data may, of course, not be required. Parts III and IV of this report discuss many qualitative techniques which can be successfully employed when conducting an assessment for mussels. Quantitative procedures are needed if the investigator desires to make an estimate of the percentage or number of a certain species in a large population. For example, in the upper Mississippi River the Higgins' eye mussel, Lampsilis higginsi, is fairly common in certain areas. An investigator might desire to determine how many L. higginsi are in a certain reach of river that is about to be dredged. In another situation, a series of shell samples from an archeological site may contain a particular number of a very rare species. Quantitative techniques can aid in determining the number of these organisms in an area or the likelihood of finding them through additional surveys.

118. A rapid method for determining number of samples necessary when investigating a population is to calculate the cumulative mean of a few samples obtained in a pilot survey. A cumulative mean (or running average) consists of taking the average of samples 1 and 2; then of samples 1, 2, and 3 (first, second, and third, etc.); then of samples 1, 2, 3, and 4 (and so on), until all samples have been included. If the results are displayed (see Figure 5-2), the plot of mean values will stabilize as more and more samples are included. In a population with a random distribution (when the variability is fairly low), the mean stabilizes quickly (see Table 5-3). In the cluster distribution (see Table 5-4), the variation is quite high and the total cumulative mean stables slowly. In the example given in Table 5-3, the plot for the random distribution stabilizes at about 8 or 10 samples. In the cluster

distribution pattern, the line never stops fluctuating, although as can be seen in Table 5-4, after about 15 samples the data begin to stabilize.

119. A more sophisticated technique is described by Green (1979). A preliminary or pilot survey is taken from the population, and individual counts are made from each collection to calculate the sample mean and standard deviation. The following formula is then used:

$$\bar{X} \pm t_{1(1/2)} = S/n^2$$

where $\bar{X}$ is the sample mean, t is the t statistic, n is the number of samples, and S is the standard deviation. In the following examples, assume that an investigator wishes to estimate the mean density of a species in a population within 10 percent of the actual number and with a 1-in-20 chance of being wrong. The t value is unknown and is a function of $n-1$ degrees of freedom; however, for fairly large samples sizes, t is a weak function of n and is approximately 2.

120. A pilot survey consisting of 3 samples was taken from a randomly distributed population; the sample mean and standard deviation were 23.67 and 5.03, respectively. When the above formula was used, the number of samples required was estimated to be 18 (Table 5-5). For this population, about 18 samples would be needed to make an estimate of the true population mean (i.e., 19.871, see Table 5-5) to within of 10 percent of the mean 19 out of 20 times. When 5 sets of samples ($n = 3$) were taken from the population, only 1 set of samples ($n = 3$) yielded a sample mean (19.3) within 10 percent of the true population mean of 19.871. In a second test, n equalled 5 and 5 more sets of samples were taken. In this case, 3 of the 5 sets of samples ($n = 5$) yielded a mean within 10 percent of the population mean. Finally, 5 sets of samples were collected with $n = 20$. All 5 sets yielded mean values within 10 percent of the known mean. In other words, the formula works. A total of 20 samples from this population yielded a mean within 10 percent of the population mean five out of five times.

121. In another test (Table 5-6) a pilot survey was taken from a population with a clumped distribution. In this case the pilot survey ($n = 3$) yielded a mean of 25.6 and a standard deviation of 23.34. It was estimated that more than 300 samples would be required to accurately sample this population. As shown in Table 5-6, one set of samples with $n = 3$ and no samples with $n = 20$ yielded an estimated mean that was within 10 percent of the actual population mean. Three out of 5 samples with $n = 100$ and all 5 samples with $n = 200$, were within 10 percent of the true mean. In this case, it appears that the formula slightly overestimated the number of samples that would be required.

122. As these two tests demonstrate, with a high variability the required number of samples can get to be quite large. To some investigators, sampling 20 times from a population is unrealistic; 300 times would cause an expenditure of time and money that probably is beyond the resources of most projects. However, the number of samples required decreases dramatically if a lower precision is acceptable. For example (see Table 5-5), if data within 20 percent of the mean in the randomly distributed population is acceptable, n would equal 4 instead of 18. As inspection of the formula indicates, when the standard deviation in comparison with the mean is high, many samples will be required to provide a good estimate of the true population mean.

123. The above examples illustrate the problems of identifying a particular species in a population of organisms. Often the investigator needs to be certain that he has collected all (both common and uncommon) organisms in an area. A plot of cumulative species versus cumulative individuals (Figure 5-3) illustrates a graphic method for estimating number of species at a site. When the Ouachita River was sampled with a 1.0-sq m quadrat, 4 species were identified after 100 individuals had been processed. After over 1400 individuals had been examined, only 8 species had been identified. On the other hand, a very diverse mussels bed in the Big Black River yielded 16 species after only 200 individuals had been processed. When the two curves are compared, it is clear that additional work at the Big Black River would yield more species; on the other hand, the Ouachita River probably did not support

many additional taxa. The curve for the Big Black River was very steep and ended abruptly, it appears that additional work is needed to find more species for this area.

Summary

124. While quantitative data may not be necessary in a mussel survey, there are techniques for determining the number of samples required to provide a fairly accurate estimate of a population mean. The simplest and fastest is to calculate cumulative means for a particular species collected in a series of samples. The resulting curve will eventually stabilize near the mean of the population. The more variable the data (i.e., if samples are taken from a cluster or other distribution where the standard deviation is high), the larger the number of samples required. A more accurate technique is to conduct a pilot survey, determine the average and standard deviation of the sample, and decide what degree of precision is required. Based upon the pilot survey, it is possible to make an estimate of the number of samples needed to satisfy the particular criteria desired.

125. The diversity of the habitat and likelihood of capturing additional, less common, species can be easily determined by plotting cumulative species versus cumulative individuals. If the area has a low diversity, the curve will level out after a few individuals have been processed. If there is a likelihood of capturing additional species, the curve will be steep and not become level until many samples have been taken.

126. WES has a computer program which can provide assistance in determining the number of samples required. The program can simulate cluster, random, or uniform distribution patterns. Using random numbers, the program then "samples" the array and calculates sample means and standard deviation. The investigator can use this program to determine how many samples are needed when analyzing certain types of populations.

Table 5-1

Habitat Variables to Measure During an Ecological Survey for Presence of Mussels

Variable	Justification for Measurement
Water depth	Most mussels inhabit fairly shallow water
Water velocity	Moving water is a requirement for most unionids
pH	Indicative of available carbonate
Total hardness	A measure of divalent cations, especially calcium and magnesium, which are used for the shell
Total alkalinity	A measure of the capacity of water to reach with hydrogen ions down to a pH of 4.5. Usually caused by bicarbonates, carbonates and hydroxides, but also borates, phosphates and silicates
Turbidity and/or suspended solids	Can interfere with the ability of mussels to feed efficiently
Particulate organic matter	A measure of the food supply in water for filter feeders.
Partical size distribution of sediments	Certain species often are found in specific types of substrate
Percentage of organic matter in sediments	Certain species often are found in specific types of substrate

Note: In a study of Canadian Lakes, Green (1972), using multivariate statistics, determined that alkalinity, pH, and sodium chloride (and not sediment variables) were the important variables in the study of distribution of mussels.

Table 5-2

Mussel Bed Comparisons

Mussel Bed Characteristics	Big Black River, Mississippi	Ouachita River, Louisiana
Number of taxa	17	6
Species diversity	1.4-2.8	0.0-0.9
Bivalves/sq m	94.3	102.0
Corbicula/sq m	0.7	95.7
Plectomerus dombeyana/sq m	27.7	4.9
Biomass (gm/sq m)	534.5 (±15.2)	106.7 (±3.9)
Depth	50 cm	4.0 cm
Substrate	Gravel, sand	Mud

Table 5-3

Cumulative Means From a Series of Randomly Collected Samples

Taken From a Population with Random Distribution

Observation	No. of Individuals (X)	Sample Mean ($\bar{X}$)
1	12	12
2	21	16.5
3	16	16.3
4	27	19
5	15	18.2
6	27	19.6
7	25	20.4
8	15	19.8
9	25	20.3
10	21	20.4
11	25	20.8
12	19	20.6
13	15	20.2
14	25	20.6
15	22	20.6
16	23	20.8
17	19	20.7
18	20	20.6
19	24	20.8
20	23	20.9
21	23	21.0
22	21	21.0
23	22	21.1
24	27	21.3
25	22	21.4
Total	534	-
Standard deviation	4.16	-
Standard error of the mean	19.48	-

Table 5-4

Cumulative Means From a Series of Randomly Collected Samples

Taken From a Population with Cluster Distribution

Observation	No. of Individuals (X)	Sample Mean ($\bar{X}$)
1	1	1
2	4	2.5
3	13	6
4	0	4.5
5	1	3.8
6	21	6.6
7	1	5.9
8	1	5.2
9	18	6.6
10	37	9.7
11	6	9.4
12	4	8.9
13	5	8.6
14	1	8.1
15	10	8.2
16	18	8.8
17	4	8.5
18	1	8.1
19	17	8.6
20	0	8.1
21	14	8.4
22	5	8.3
23	16	8.6
24	6	8.5
25	31	9.4
26	11	9.5
27	8	9.4
28	0	9.1
29	2	8.8
30	44	10.0
31	0	9.7
32	2	9.4
33	1	9.2
34	0	8.9
35	6	8.8
Total	309	-
Standard deviation	10.9	-
Standard error of the mean	123.5	-

Table 5-5

Variation on Mean Number of Organisms When Sampling From a Randomly Distributed Population

No. of Samples	Mean	Standard Deviation	Within 10% of Mean (*)
3	16.2	3.0	
	16.7	3.2	
	19.3	1.5	*
	22.3	4.0	
	23.7	5.8	
	19.6**	3.3†	
5	19.0	5.0	*
	19.6	3.6	*
	20.4	1.9	*
	22.4	3.9	
	22.8	1.6	
	20.8**	1.7†	
20	18.7	4.0	*
	19.6	3.2	*
	19.8	3.7	*
	19.9	4.0	*
	20.2	3.5	*
	19.6**	0.6†	

Population mean = 19.871

Pilot survey:

n = 3

Mean = 23.67

Standard deviation = 5.03

Number of samples required:

$$2.367 \cong (2)\ \frac{5.03}{\sqrt{n}}$$

$$18 \cong n$$

** Average of means for this number of samples.

† Standard deviation among the five means for this number of samples.

Table 5-6

Variation on Mean Number of Organisms When Sam ling From a Cluster Distribution

No. of Samples	Mean	Standard Deviation	Within 10% of Mean (*)
3	19.7	12.6	
	25.7	25.0	
	33.7	46.4	*
	37.3	21.8	
	38.6	33.5	
	31.0**	8.1†	
20	25.6	21.8	
	26.1	25.0	
	36.2	25.9	
	37.4	26.3	
	44.9	31.4	
	34.0**	8.2†	
100	32.8	26.7	*
	33.9	27.4	*
	35.5	24.8	*
	36.2	27.7	
	38.6	27.3	
	35.4**	2.2†	
200	29.2	25.9	*
	29.7	25.2	*
	31.9	25.6	*
	32.3	26.5	*
	33.8	29.6	*
	31.4**	1.9†	

Population mean = 32.389

Pilot survey:

n = 3

Mean = 25.6

Standard deviation = 23.34

Number of samples required:

$$2.56 \cong (2)\ \frac{23.34}{\sqrt{n}}$$

$$332 \cong n$$

** Average of means for this number of samples.

† Standard deviation among the five means for this number of samples.

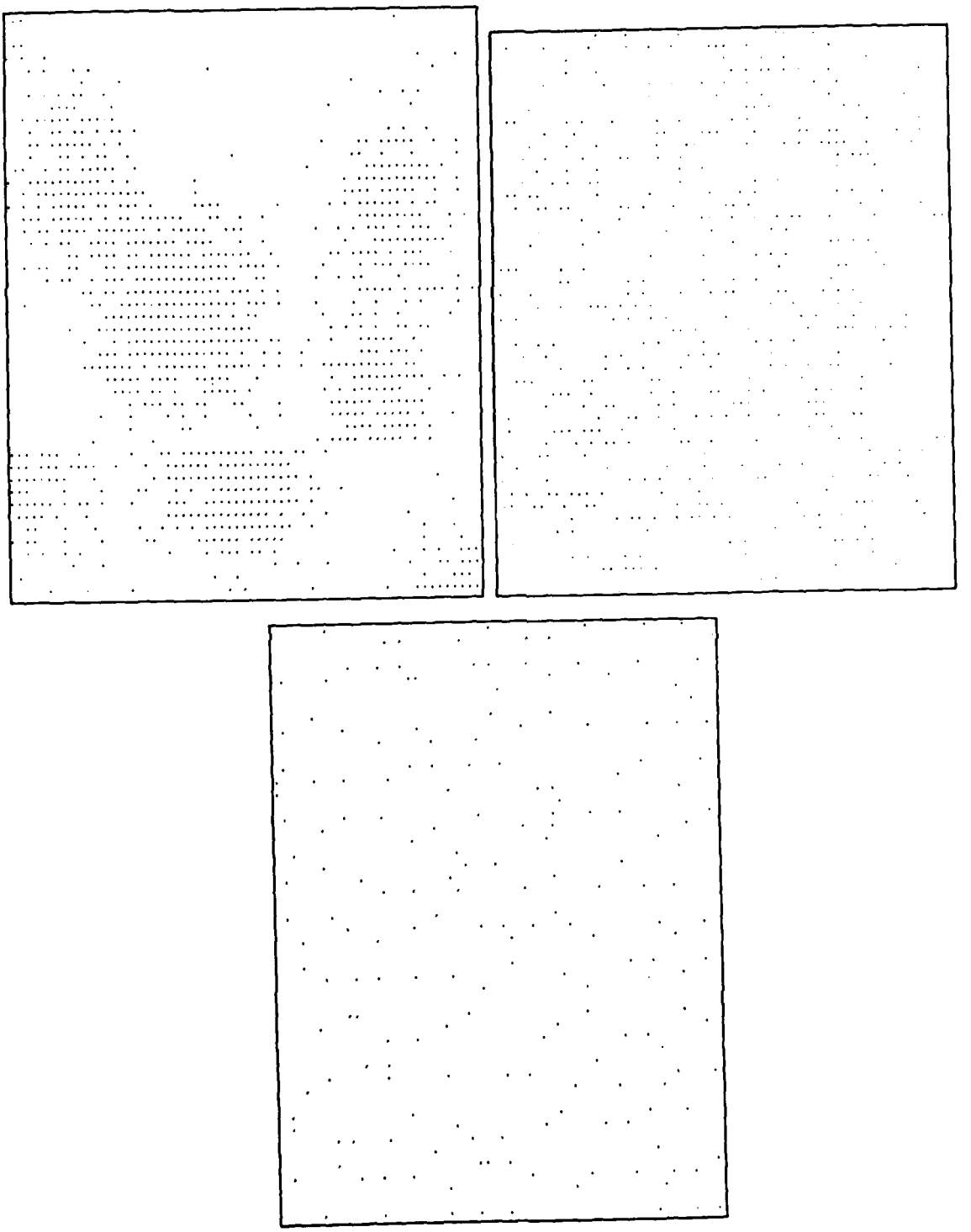

Figure 5-1. Distributions simulated by the FORTRAN program IMAT

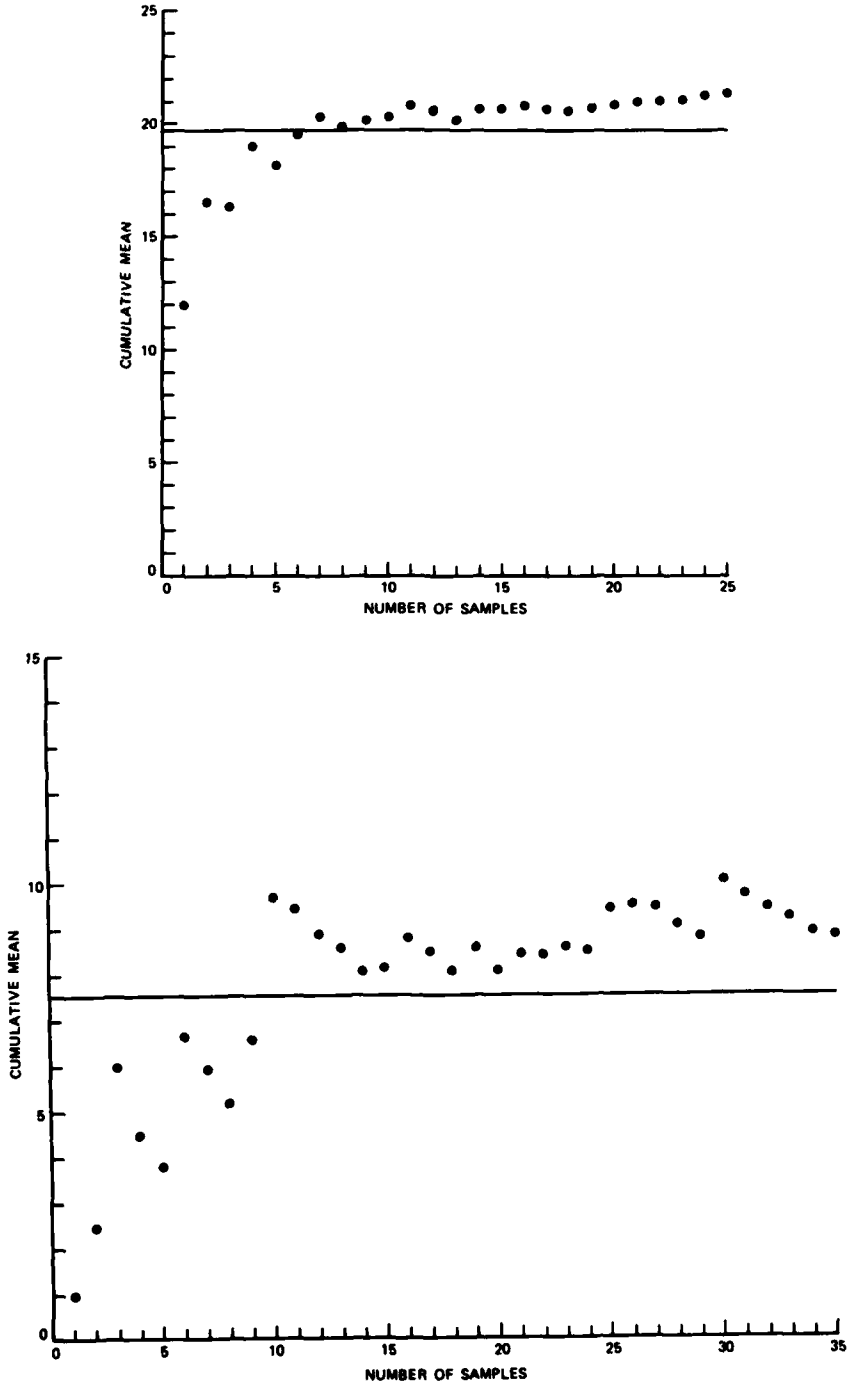

Figure 5-2. Cumulative means when sampling a random (top) and cluster (bottom) distribution

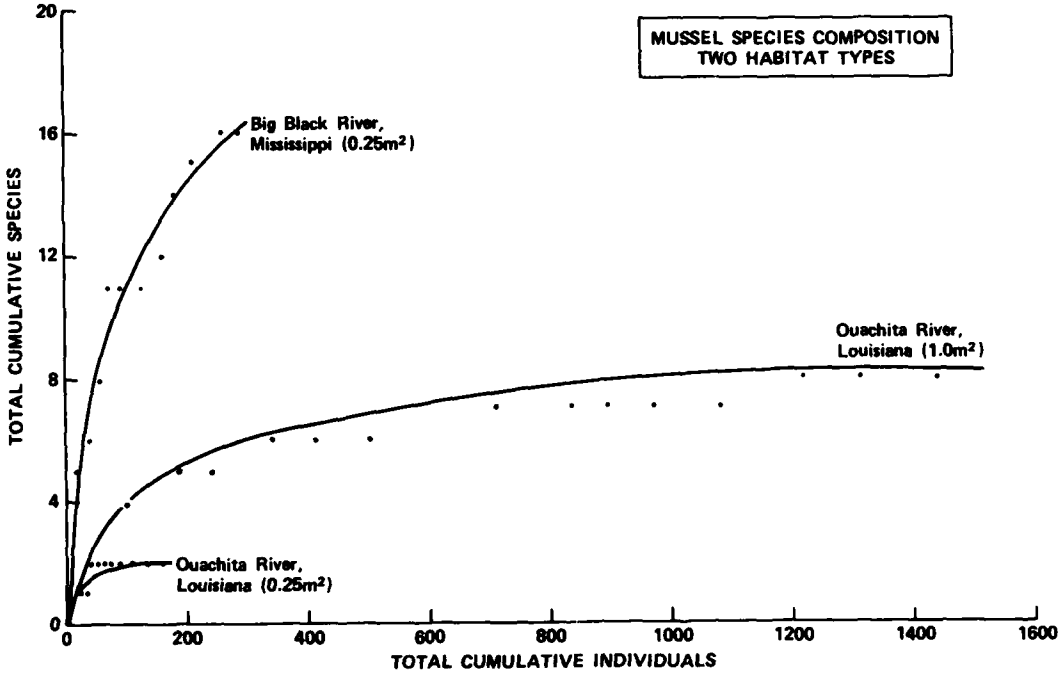

Figure 5-3. Number of species versus number of samples for a diverse mussel bed in the Big Black River, Mississippi (top), and a low-diversity bed in the Ouachita River, Louisiana (bottom)

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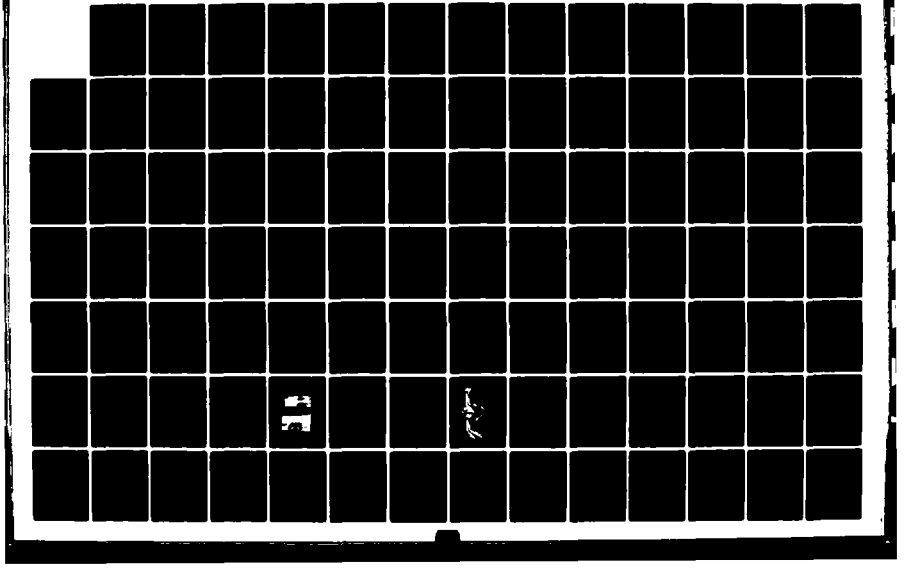

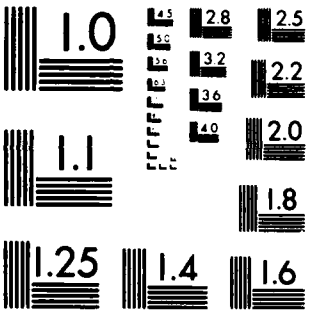

PART VI: COORDINATION WITH COMMERCIAL SHELL FISHERMEN

Introduction

127. Professional shell fishermen operate in many of the medium-sized and large rivers and lakes in the Central and Eastern United States. They collect live mussels using brail, SCUBA, or other devices. The collected specimens are sorted to size and species and sold to a shell buyer who cooks or steams the animals to remove the meat from the shell. The shells are then packed into canvas sacks and taken by rail to the West Coast where they are shipped to China or Japan for the commercial pearl industry. When they reach their final destination, they are processed into spherical beads which are then inserted into pearl oysters (Margaritana sp.) to form the nucleus of a saltwater pearl. For more information on the professional shell industry see Peach (1982). Description of commercial sampling for mussels is found in Parmalee (1967), Kunz (1894, 1898a, 1898b), Carlander (1954), Coker (1914, 1919), Smith (1899), Simpson (1899), Smith (1919), van der Schalie (1938), Krumholz et al. (1970), Jorgenson and Sharp (1971), and Rasmussen (1980).

Availability of Data

128. Because of their interest in collecting high-quality shells for use in the pearl industry, the professional shell fishermen are usually quite knowledgeable about mussels in certain areas. They are interested only in shells of commercial interest, i.e. those that are nonbrittle, fairly thick, and have white nacre. Typically the uncommon, unusual, or endangered species are not of much use for commercial purposes. Some of the information that can be provided by professional shell fishermen includes:

a. Information on whether or not mussel beds or shells can be found in a certain area.

b. Possible dangers at specific locations.

c. Possible ownership or right-of-way problems.

d. Background information on fish, substrate types, and current.

e. Assistance with boats and collecting equipment.

f. Professional collecting assistance (i.e., using SCUBA or brail).

Because of their interest in the shells, the professional shell fishermen should be consulted while sampling an area for the first time.

129. When a particular water resource project or maintenance activity will irretrievably damage a mussel bed of commercial value, the Federal agency concerned should consider contacting any commercial shell harvesters in the area before the habitat is disturbed. Cooperatively, the commercial operators who wish to do so can exploit the area while the Federal aquatic biologist connected with the project can obtain complete data on species distribution and abundance.

130. In most states commercial mussel fishermen must obtain licenses from an agency of the State government to legally pursue their trade. Lists of persons who have been granted licenses may be available from those agencies. WES has worked with three commercial shell companies: American Shell Company, Knoxville, Tenn. (Mr. J. L. Peach), Tennessee Shell Company, Camden, Tenn. (Mr. J. R. Latendresse), and M. D. Cohen and Son, Inc., Terre Haute, Ind. (E. Nelson Cohen).

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PART VII: CLEANING AND PRESERVING FRESHWATER MUSSELS

Introduction

131. Certain species of mussels can be accurately identified only after they have been cleaned. A clean, well-preserved and maintained collection aids in the rapid and accurate identification of freshwater mussels. The following describes methods for cleaning and preserving the shells of freshwater mussels. In addition, techniques for relaxing and opening mussels and for preserving the viscera (soft tissue) are presented.

Live Material

132. In many field surveys for mussels, the majority of the collection is composed of dead or empty valves. Such shells are often of an undetermined age and origin. For this reason every effort should be made to collect some live material from the area under study. The existence of live mussels is an accurate reflection of the environmental characteristics of the habitat under investigation. When collecting live material, be aware that freshwater mussels of any type are a valuable resource that deserve protection. Take only a few representative specimens; in addition be careful not to sacrifice extremely rare or uncommon species inadvertently. For assistance in identification of the federally listed endangered bivalves, see Clarke and Fuller 1983. Parts IX and X of this document present information on the safe handling and transportation of living mollusks.

133. Since many identifying features of mussels are internal shell characteristics, some living specimens will have to be sacrificed for positive identification. In some cases (e.g., in distinguishing Fusconaia from Pleurobema), examination of soft parts may be necessary for identification. Live mussels can be opened by first cutting the anterior and posterior adductor and retractor muscles. This is accomplished by inserting a

knife between the shells and moving it anteriorly and posteriorly (it is easy to break the blade of a small knife when trying to open the larger, heavy-shelled species). Opening the shells with a knife will partially destroy the soft tissue: do not use this technique if the parts are to be retained for study. Specimens can also be opened by soaking a few minutes in hot tap water or heating them to boiling in a container of water; the shells will gape open after this treatment. With the shells partially opened, the muscles are fairly easy to cut at the points of attachment.

134. Many museum personnel and other workers use chemical muscle relaxants when working with live material (Clench 1931, Wolfert and Hiltunen 1968, Baker 1921, and van der Schalie 1953). Their use ensures that the specimens will be killed humanely and prevents the contraction of the foot and other organs which occurs when specimens are boiled or plunged into preservative; such distortion reduces the value of the specimens for anatomical study. While many relaxants have been used (see Table 7-1 for a list of suggested chemicals), Nembutal and Chlorobutanol are two commonly used compounds which are effective. A small amount of a relaxant is added to the water containing specimens; the amount and the frequency of further additions of relaxant depend on the chemical being used. Often it takes more than 24 hrs to fully relax the specimen so that the foot is protruding from the open shell and it does not respond when touched. Specimens may also be relaxed and killed by immersing them in water in a plastic bag and freezing everything in a freezer; they should then be thawed and quickly preserved. Occasionally mussels die from lack of oxygen or shock before they become relaxed; so unless there is some specific reason to relax the specimens, many collectors open shells with a knife or hot water.

135. If the soft parts are to be part of a voucher or study collection, they should be "fixed" by soaking in a 10 percent solution of buffered formaldehyde* for a day or two. After the formaldehyde

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* Bovin's solution (picric acid, formaldehyde, and glacial acetic acid) is also used to fix tissues.

treatment, rinse the tissues thoroughly in tap water, put them through a dehydration series of progressively higher percentages of alcohol, then permanently preserve them in 70 percent ethyl alcohol. Some workers who do not like to use formaldehyde to fix tissues and kill, relax, and preserve specimens in a mixture of ethyl alcohol, glycerin, and distilled water (Morris and Taylor 1978). This latter technique is safe and by far the easiest method for most work; however, it will not fix the tissues, and specimens will be unsuitable for histological work.

Cleaning and Preserving Shells

136. Many of the uncommon specimens can be identified only after the shells have been cleaned. To facilitate cleaning, soak the shells in warm water for several hours. Sand, mud, algae, and other material can usually be removed by briskly brushing the surface with a stiff toothbrush or a nylon scouring pad. For particularly hard-to-clean shells, a brief soaking in a 5 to 10 percent solution of Clorox is effective. While this treatment does alter the microstructure of the shell (Carriker 1974), it should provide no problems for general use. Household cleaners are often useful for cleaning shells. Some workers dip shells for less than 5 sec in a 10 percent solution of hydrochloric acid, then rinse completely in running water. Both the Clorox and hydrochloric acid rinses are effective but potentially damaging to valuable specimens; these techniques should therefore be used carefully and not on unusual or uncommon specimens where subtle colors of the nacre and periostracum could be important for identification.

137. Once they have been cleaned and have begun to dry, some shells may begin to crack or actually break apart. This is most noticeable with the thinner shelled types, such as the floater (Anodonta imbecillus) or fragile paper shell (Lepdodea fragilis). Thicker

specimens such as the three ridge (Amblema costata) or ebony shell (Fusconaia ebena) will not crack, although some of the periostracum will gradually flake away. Some workers prevent this from happening by dipping the shells in a preservative to prevent further chipping or flaking (see Table 7-2 for a list of eight preservatives and directions for their use). The most commonly used material is a solution of xylene and paraffin, although vaseline, shellac, and baby oil serve the same function. While the xylene-and-paraffin mixture requires a little time to prepare, it provides the best all-around protection for shells and does not rub off or have any objectionable "greasy" feel. Additional information on cleaning and preserving shells appears in Bales (1974), Dall (1892), and Wetherby (1882).

138. Heavily weathered or archeological material can be preserved with a dilute methyl cellulose solution. Shells and fragments can be soaked in this solution, or the liquid can be applied with a small brush. The methyl cellulose can be prepared by dissolving a household cement such as Duco cement in acetone (1 part glue to 1 or 2 parts solvent).

139. It should be pointed out that some museums in the United States use no special cleaning or preserving techniques for their shells. This is because the subtle colors and irridescence are often altered by cleaning and preserving techniques. Many collectors do not use any special techniques to clean or preserve shells. Carefully executed cleaning and preserving methods are required principally for display specimens that will be handled frequently or for those species that are likely to crack or chip easily.

Table 7-1

Various Types of Muscle Relaxants Used with Freshwater Mollusks*

Sodium salt of pentobarbital (Nembutal)
Chloral hydrate
Chloretone
Chlorobutanol
Ethyl
Alcohol
Menthol
Nicotine
Chloroform
Ether
Crystalline menthol dissolved in methanesulfonate (TMS or MS 222)
Crystalline methanol
Magnesium chloride
Magnesium sulphate
3-Trifluormethyl-4-nitrophenol (TFM)
3, 4, 6-Trichloro-2-nitrophenol
Ethyl alcohol (80%), glycerin (5%), distilled water (15%)
a Styrylpyridine
Propylene phenoxytol

* Results are not consistent: complete relaxation may take from 12 to 36 hrs under various conditions.

Note: For more information see Wolfert and Hiltunen (1968) and Runham et al. (1965).

Table 7-2

Methods for Preserving Shells

Compound	Direction for Use	Remarks
Paraffin (1 lb) and xylene (1 gal)	The paraffin and xylene will take up to one week to dissolve and should be stored in a dark container. Shells are dipped once in the mixture and allowed to air dry under a hood (Note: This mixture is both toxic and flammable)	Dries in several hours to a dry, nearly colorless finish. A commonly used and preferred method
Petroleum jelly	Rub a small amount on the shell and wipe off excess with a tissue	Shells have a "greasy" feel, and the periostracum becomes darker after application
Mineral oil and mineral spirits (equal amounts of each)	Rub a small amount on the shell and wipe off excess with a tissue	Shells have a "greasy" feel, and the periostracum becomes darker after application
Clear fingernail polish	Paint a thin strip along the edge of the shell	Dries to a clear hard finish and adds strength to the edge. Changes the appearance of the edge of the shell but inhibits cracking and breaking of fragile specimens
Baby oil	Rub a small amount on the shell and wipe off excess with a tissue	Shells have a "greasy" feel
Varnish, shellac, or methyl cellulose	Paint on both sides with a brush, or dip shells in a container filled with the preservative	Dries to a hard finish but changes the appearance of the shell; inhibits cracking
Water	Store shells in a zip-lock plastic bag with a few drops of water	No permanent effect on color or lustre of the shell. There is the possibility of fungal or bacterial growth
Alcohol (50-70%)	Store in a suitable container	Some pigments could become lighter in time. The alcohol should prevent the growth of bacteria and fungi.

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VIII: IDENTIFYING FRESHWATER MUSSELS

Sorting and Identification

140. Probably the first step in the identification of a large collection of mussels is to sort the material into as many groups as possible based on obvious identifying features. While the subtle taxonomic features of some species are visible only after careful cleaning (see Part VII), this step may not be necessary for common species. After the easy-to-identify taxa have been counted and recorded, study (and clean as necessary) the unknowns carefully to be certain that they are not unusually shaped members of the known species. Many times a group of unknown organisms actually contains two or three closely related species. Many species exhibit variations in shell morphology depending upon the characteristics of the habitats where they were collected (see Clarke and Fuller 1983). Species which can exhibit a wide range of variable shell features are the pigtoes (Pleurobema cordatum complex, Fusconaia sp.), the three ridge (Amblema plicata), and the washboard (Megalonais gigantea). Almost all shells will be more inflated and thicker in slow-moving rivers or lakes than they will be at headwater streams (Ball 1922). Total calcium in the water also exerts an effect; in soft, acidic habitats, shells are often pitted and eroded; while the shells in very alkaline, high-pH waters are typically thicker and less eroded (Grier 1920, Clarke and Berg 1959, Harman 1969).

141. Certain representatives of the genus Pleurobema, Actinonais, Lampsilis, and Anodonta, as well as incomplete or badly eroded specimens are difficult for the beginner to identify. However, with very little experience the heelsplitters (Proptera alata, Lasmigona complanata), the fluted shell (Lasmigona costata), and the pistol grip (Tritogona verrucosa), among others, are usually easily to identify if a good field guide is available.

Identification Guides

142. There are many published field guides and taxonomic keys available to aid in the identification of many common and a few uncommon mussels (see Table 8-1). Most contain either photographs or line drawings of shells, as well as data on ecology, natural history, and range. Because of the considerable variation in the external morphologies of many species, publications that pertain to the geographic area under study should be consulted. Publications of particular value to the amateur or beginner include the guides by Parmalee (1967) and Murray and Leonard (1962). Specific information on range, habitat requirements, and identifying features of the federally listed mussels is in Clarke and Fuller (1983). See Table 1 for a taxonomic key to freshwater mussels.

Obtaining Assistance

143. A local museum is an excellent resource for assistance in identifying freshwater mussels. If a personal visit is planned, contact the facility in advance to be certain when visitors can be accepted. The curators may be willing to help in the identification in exchange for specimens. Do not waste their time with dirty or poorly organized material. If the mussels are to be donated to the museum, include accurate data on location (county, river name, and river mile). Do not use unique station codes which have meaning only to the collectors. Any available data on water chemistry, flow, water depths, or other characteristics of the habitat where the specimens were collected should be included. The museum curators will be particularly interested in unusual material or specimens taken from areas about to be altered by water resource or other projects. Table 8-2 contains a listing of museums with reference collections which can be used to help identify unknown material. For more information on the use of museums as a resource, see Hartfield (1982), Solem (1975), and Stansbery (1975).

144. In the event assistance is needed to either collect or identify mollusks, a list of consultants (Table 8-3) has been provided.

However, the biologist's own expertise in collecting and identifying mussels will ensure a higher quality product if the study is to be conducted by a consultant. In addition, the biologist can save time and money if he has the expertise to collect and identify shells without having to resort to a consultant in all situations.

Nomenclature Problems

145. Van der Schalie (1950) reviewed the sources of the problems with the nomenclature of North American naiads. He describes in some detail the careful work by Ortman, Walker, and Pilsbry to straighten out the earlier work of Rafinesque which had confused naiad systematics. However, Morrison (1969) pointed out that efforts of Ortmann and his two colleagues were incomplete for two reasons: (a) the then incomplete rules of nomenclature allowed them to decide against first priority of dates and (b) they worked primarily with selected adults and did not approach Rafinesque's monograph, which laid out all of the Ohio and Kentucky species. The result of this confusion is the use of more than one name for the same genus or species. For example, the Federal list of endangered species uses the genera Toxolasma for Carunculina and Epioblasma for Dysnomia. Stansbery (1976) also uses Epioblasma, while Johnson (1978) prefers use of the genus name Plagiola, which he considers to be the earliest available generic taxon. More information on the nomenclature problems associated with freshwater mussels can be found in Stansbery (1982).

Table 8-1

Taxonomic Key to Common Freshwater Mussels (Unionacea)

of Northeastern North America*

1. Articulating hinge teeth absent or vestigial. Posterior slope without ridges crossing lines of growth 2

   Articulating hinge teeth present. Posterior slope with or without ridges crossing lines of growth 9

2. Vestigial pseudocardinal teeth indicated by a more-or-less prominent depression and thickening just anterior to beak. Ridges of beak sculpture without a central sinuation 3

   Pseudocardinal teeth entirely absent. Ridges of beak sculpture with a central sinuation 4

3. Nacre usually with salmon or pink suffusions near the beak cavity. Shell thin but does not usually crack extensively on drying. Beak sculpture coarse; bars sharply angled on posterior ridge. Adults often exceeding 75 mm in length. St. Lawrence and Atlantic Drainages ..... Strophitus undulatus

   Nacre usually bluish white, without salmon or pink suffusions. Shell thin, often cracking extensively on drying. Beak sculpture fine; bars not sharply angled on posterior ridge. Adults very seldom exceeding 75 mm in length. St. Lawrence Drainage only ..... Anodontoides ferussacuanus

4. Beaks flattened and not projecting above hinge line. Hinge line straight. Shell thin and fragile. Periostracum greenish and shiny. Beak sculpture interrupted ..... Anodonta imbecillis

   Beaks inflated and projecting above hinge line 5

5. Nacre salmon or copper colored. Shell prominently thickened anterior-ventrally. Ridges of beak sculpture with shallow sinuations and without nodules. Atlantic Drainage .. Anodonta implicata

   Shell not as above 6

(Continued)

* Applicable to the Atlantic Drainage from Labrador to Delaware including the lower St. Lawrence Drainage east of Niagara Falls. From Clark and Berg 1959.

Table 8-1 (Continued)

6. Atlantic Drainage. Shell variable, fragile, periostracum usually greenish and shiny, sometimes brownish and not shiny. Beak sculpture ridges sinuous and without nodules ..... Anodonta cataracta

   St. Lawrence Drainage 7

7. Beak sculpture fine, concentric, oblique, not sinuous. Hinge line slightly curved. Nacre bluish white. Adults very rarely exceeding 75 mm in length ..... Anodontoides ferussacianus

   Beak sculpture sinuous. Hinge line straight. Nacre silvery, white, or bluish white. Adults usually exceeding 75 mm in length 8

8. Periostracum green or greenish and shiny. Beak sculpture not nodulous ..... Anodonta cataracta

   Periostracum brown or brownish and not shiny. Beak sculpture usually nodulous ..... Anodonta grandis

9. Shell sculptured on posterior slope by ridges crossing lines of growth 10

   Shell not sculptured as above 13

10. Shell short (height/length >0.68), subrhomboid, massive, and thick anteriorly. Posterior two-thirds traversed by large and prominent ridges ..... Amblema plicata

    Shell more elongate (height/length <0.65). Sculpturing on posterior slope only 11

11. Shell relatively compressed (width/height <0.60). Posterior ridge low and rounded. Interdental tooth prominent. Shell usually not prominently and extensively rayed. Length often exceeding 100 mm ..... Lasmigona costata

    Shell relatively inflated (width/height >0.60). Posterior ridge inflated and prominent. Interdental tooth absent. Shell often prominently and extensively rayed. Length very rarely exceeding 100 mm 12

12. Posterior ridge inflated and rather sharp. Adult specimens often exceeding 70 mm in length. Shell sharply truncated. Periostracum extensively rayed, darker anteriorly, and lighter posteriorly. St. Lawrence and Susquehanna Systems only ... Alasmidonta marginata

(Continued)

Table 8-1 (Continued)

Posterior ridge inflated and rounded. Adult specimens rarely exceeding 70 mm in length. Shell not sharply truncated. Periostracum more or less extensively rayed, lighter anteriorly and darker posteriorly. St. Lawrence System east of Lake Ontario and Atlantic Drainage ..... Alasmidonta varicosa

13. Interdental tooth in left valve more or less well developed and articulating, with interdental depression in right valve. Pseudocardinal teeth directed forward. Nacre not purple 14

Shell not as above 15

14. Adults usually exceeding 70 mm in length. Interdental tooth large and prominent. Specimens smaller than 70 mm, with a low, more or less prominent posterior wing. St. Lawrence System and upper Hudson River System ..... Lasmigona compressa

Adults not known to exceed 65 mm in length. Interdental tooth small. Adult specimens without a posterior wing. Lake Ontario Drainage in New York, Erie Barge Canal, and Susquehanna System ..... Lasmigona subviridis

15. Articulating lateral teeth short, poorly developed, or absent ...16

Articulating lateral teeth elongate and well developed 18

16. Adult length usually exceeding 90 mm. Height/length usually 0.50. Valves often arcuate. Periostracum dark and rayless .... Margaritifera margaritifera

Adult length less than 90 mm. Height/length 0.50. Valves not arcuate. Periostracum often rayed 17

17. Valves ovate or triangular ovate, prominently thickened anteriorly, and with maximum inflation near middle of shell. Atlantic Drainage and St. Lawrence System ..... Alasmidonta undulata

Valves subrhomboid, not prominently thickened anteriorly, and with maximum inflation ridge. St. Lawrence System only .... Alasmidonta calceola (=A. viridis)

18. Adults small, not exceeding 50 mm in length. Lateral teeth double in right valve and single in the left. Periostracum brown and without rays. Atlantic Drainage only ..... Alasmidonta heterodon

(Continued)

Table 8-1 (Continued)

Lateral teeth single in the right valve and double in the left ..19

19. Shell subovate, compressed, comparatively thin, and medium to large, usually with a prominent dorsal wing 20

Shell without a prominent dorsal wing and not as above 21

20. Periostracum dark brown or nearly black; nacre purple to pink; pseudocardinal teeth compressed, strong, and well developed .... Proptera alata

Periostracum yellowish or light brown; nacre silvery white, sometimes pinkish dorsally; pseudocardinal teeth thin, weak, and poorly developed ..... Leptodea fragilis

21. Shell elongate (height/length < 0.48) and subcylindrical (width/height > 0.60) or both. Periostracum brownish-black to black and not extensively rayed 22

Shell less elongate (height/length > 0.48) and more compressed (width/height < 0.60). Periostracum variable 23

22. Shell medium-sized, less than 110 mm long. Posterior end extended and bluntly pointed centrally. Nacre purple or white. Atlantic Drainage and St. Lawrence System ..... Ligumia nasuta

Shell large, usually more than 110 mm long. Posterior end rounded and somewhat extended. Nacre white or tinged with purple dorsally. St. Lawrence System only ..... Ligumia recta

23. Shell regularly ovate or short elliptical, heavy, thick anteriorly, and with massive teeth. Beaks greatly swollen, pointed forward, and near or at the anterior end. Length less than 70 mm. St. Lawrence System only ..... Obovaria olivaria

Shell not as above 24

24. Nacre purple 25

Nacre white, pinkish, or orange 26

25. Shell variable, usually subrhomboid, discs flattened, posterior obliquely subtruncate. Shell rather compressed; if more inflated, then broadest near posterior slope. Beaks not close to anterior

(Continued)

Table 8-1 (Continued)

end. Very common. Atlantic Drainage and St. Lawrence System .... Elliptio complanata

Shell variable, usually subelliptical, discs somewhat convex, posterior slightly extended and tapered. Shell broadest anteriorly. Beaks close to anterior end. Uncommon. St. Lawrence System only ..... Elliptio dilatata

26. Shell very small, usually not exceeding 35 mm. Ovate, relatively thick and strong, and with well-developed hinge teeth. Periostracum usually blackish, without rays, and roughened by lines of growth. St. Lawrence Drainage only ..... Carunculina parva

Shell larger and not as above 27

27. Shell relatively small (45 to 65 mm long), subrhomboid, not ovate, relatively thin and compressed, especially posterior-dorsally. Wavy, wide, irregular rays sometimes present. Hinge teeth rather delicate, not serrated. Young specimens have a low posterior wing. Beak sculpture double looped. Susquehanna System, Erie Barge Canal, and Lake Ontario Drainage ..... Lasmigona subviridis

Shell not as above 28

28. Beaks near anterior end. Posterior end tapered and somewhat extended. Shell somewhat elongate and subcylindrical. St. Lawrence System only 29

Beaks not near anterior end. Posterior end not tapered and extended. Shell not elongate or subcylindrical. St. Lawrence System and Atlantic Drainage 30

29. Periostracum with prominent green or brown rays alternating with yellow. Length usually less than 75 mm. Beak sculpture ridges distinctly double looped ..... Villosa iris

Periostracum brown and without rays. Length often exceeding 70 mm. Beak sculpture ridges straight or slightly sinuate centrally, not double looped ..... Elliptio dilatata

30. Shell triangular-ovate, heavy, and with thick and ponderous hinge teeth. Height/length > 0.70. Posterior pointed basally. Periostracum without rays. St. Lawrence System ..... Fusconaia flava

Shell not as above 31

(Continued)

Table 8-1 (Concluded)

31. Shell variable, subrhomboid, posterior obliquely subtruncate. Posterior ridge present. Periostracum usually without rays. Beak sculpture concentric. Height/length usually 0.60. Very common ... . Elliptio complanata

Shell subelliptical or subovate and either more or less rayed or with a shiny, yellowish periostracum. Posterior ridge nearly absent, or height/length >0.60, or both. Beak sculpture often double looped 32

32. Shell heavy, elliptical, and with wide rays. Length often exing 120 mm. Sexual dimorphism not readily apparent. Rare. St. Lawrence Drainage only ..... Actinonaias carinata

Shell not as above 33

33. Shell medium or small (length usually less than 80 mm), relatively thin, and only slightly thickened anteriorly. Pseudocardinal teeth and interdentum thin and compressed. Sexual dimorphism well marked. Atlantic Drainage only ..... Lampsilis ochracea

Shell larger (length more than 80 mm) and substantially thicker anteriorly than posteriorly 34

34. Shell without rays or rays on posterior slope only. Periostracum yellowish and shiny. Atlantic Drainage and St. Lawrence System east of Lake Ontario ..... Lampsilis cariosa

Shell not as above 35

35. Shell subovate and usually with more or less well-developed narrow or wide rays generally distributed on a yellowish background. Height/length >0.60 in both sexes. Sexual dimorphism well marked. Posterior ridge often well developed. St. Lawrence System only ... . Lampsilis ventricosa

Rays well developed, but may be obscure in old, blackened specimens. Height/length <0.60 in nearly all males and many females. Posterior ridge low and rounded 36

36. Sexual dimorphism not prominent. Rays mostly wide. Periostracum not shiny. Nacre white or suffused with pink or orange. Atlantic Drainage and St. Lawrence System ..... Lampsilis radiata radiata

Sexual dimorphism prominent. Rays mostly narrow. Periostracum shiny. Nacre white, not suffused with pink or orange. St. Lawrence System ..... Lampsilis radiata siliquoidea

Table 8-2

A Partial List of Consultants With Expertise

in Identifying Freshwater Mollusks

Academy of Natural Sciences
19th and the Parkway
Philadelphia, PA 19103
(215) 299-1116

Biological Consultants
401 Medallion Ct.
Louisville, KY 40219
(502) 964-7207

Brice, Petrides & Associates, Inc.
191 West 5th Street
Waterloo, IA 50701
(319) 232-6531

Mr. Charles Cope
Concordia Research Office
511 Cedar
Concordia, KS 66901
(913) 243-3857

Ecological Analysts
1500 Frontage Road
Northbrook, IL 60062
(312) 564-0700

Ecological Consultants, Inc.
1900 Dexter Avenue
Ann Arbor, MI 48103
(313) 622-5959

Ecology Consultants, Inc.
118 South Riverview
Bellevue, IA 52031
(319) 872-4313

Ecosearch, Inc.
Hawthorne Street
Mattapoisett, MA 02739
(617) 758-6043 or 774-1425

Environmental Science and
Engineering, Inc.
11665 Lilburn Park Rd.
St. Louis, MO 63141
(314) 567-4600

Loras College
1450 Alta Vista
Dubuque, IA 52001
(319) 588-7231

Malacological Consultants
1603 Mississippi Street
La Crosse, WI 54601
(608) 782-7958

National Biocentric
4663 Chatsworth
St. Paul, MN 55112
(612) 484-9070

NUS Corporation
Ecological Sciences Division
Manor Oak Two
1910 Cochran Road
Pittsburgh, PA 15220
(412) 343-9200

Quincy College
1831 College
Quincy, IL 52761
(217) 222-8020

Mr. John Schmidt
Department of Natural Resources
1201 Greenbrier St.
Charleston, WV 25311
(304) 348-2837

Stanley Consultants
Stanley Building
Muscatine, IA 52761
(319) 264-6600

Tyson Research Center
Washington University
P. O. Box 258
Eureka, MO 63025
(314) 938-5346

Barry A. Vittor and Associates
8100 Cottage Hill Rd.
Mobile, AL 36609
(205) 661-7236

Dr. Paul Yokley, Jr.
P. O. Box 5135
University of North Alabama
Florence, AL 35630
(205) 766-4100 (ext 437)

Table 8-3

Institutions with Collections of Mollusks*

Institution**	Location	Collection Size, Items
	Alabama	
Birmingham-Southern C	Birmingham	4,094
U North Alabama	Florence	<5,000
U Alabama	University	>5,000
	California	
Pacific Union C	Angwin	1,000
La Verne C	La Verne	5,000
U Southern California	Los Angeles	20,000
Coyote Pt. Museum	San Mateo	10,000
	Connecticut	
Central Connecticut State C	New Britain	<5,000
	Florida	
Jacksonville U	Jacksonville	2,500
Florida Institute Technology	Melbourne	1,000
U Miami	Miami	4,000
U South Florida	Tampa	5,000
Rollins C	Winter Park	50,000?
	Georgia	
U Georgia at Savannah	Savannah	<5,000
	Hawaii	
Chaminade U	Honolulu	<5,000
	Illinois	
Illinois Wesleyan U	Bloomington	5,000
	Indiana	
Anderson C	Anderson	300
Indiana U	Bloomington	5,000
U Notre Dame	Notre Dame	900

(Continued)

* From Thompson (1982).

** C = College; M = Museum; U = University.

Table 8-3 (Continued)

Institution	Location	Collection Size, Items
	Kansas	
Emporia Kansas State C	Emporia	<5,000
Kansas State U	Manhattan	<5,000
	Kentucky	
U Louisville	Louisville	3-4,000
	Massachusetts	
Gray Museum, Woods Hole	Woods Hole	<5,000
	Michigan	
Andrews U	Berrien Springs	5,000
Northern Michigan U	Marquette	<2,000
	Minnesota	
U Minnesota	Minneapolis	<5,000
	Missouri	
NW Missouri State U	Maryville	5,000
	New Jersey	
Glassboro State C	Glassboro	5,000
	New York	
Alfred U	Alfred	
Cornell U	Ithaca	10,000
Southampton C	Southampton	20,000
	North Carolina	
East Carolina U	Greenville	3,000
	Ohio	
Mt. Union C	Alliance	1,000
Cleveland M Natural History	Cleveland	20,000
	Oklahoma	
U Science & Arts Oklahoma	Chickasha	250
U Oklahoma	Norman	2,500

(Continued)

Table 8-3 (Continued)

Institution	Location	Collection Size, Items
	Oregon	
U Oregon	Eugene	3,000
	Pennsylvania	
Bloomsburg State C	Bloomsburg	3,000
North U	Lancaster	15,000
Philadelphia C Pharmacy and Science	Philadelphia	300
Susquehanna U	Selensgrove	<5,000
West Chester State C	West Chester	300
	South Carolina	
Francis Marion C	Florence	900
	Tennessee	
East Tennessee State U	Johnson City	1,700
U Tennessee	Knoxville	1,500
U of the South	Sewanee	4,000
	Texas	
Texas Christian U	Ft. Worth	4,000
Texas A & M	Kingsville	
Stephen F. Austin State U	Nacogdoches	3,000
Wayland Baptist C	Plainview	5,000
Trinity U	San Antonio	5,000
	Utah	
U Utah	Salt Lake City	4,000
	Virginia	
George Mason U	Fairfax	1,000
Mary Washington C	Fredericksburg	5,000
U Richmond	Richmond	10,000
	Wisconsin	
U Wisconsin	Madison	5,000
U Wisconsin	Stevens Point	5,000
Carroll C	Waukesha	5,000

(Continued)

Table 8-3 (Continued)

Institution	Catalogued Units (x 1000)	Uncatalogued Units (x 1000)
	Large Institutions*	
NMNH	786	500
ANSP	377	27
MCZ	293	100
LACM	240	40
AMNH	210	40
FMNH	205	20
BPBM	160	50
DMNH	135	30
CAS	127	21

(Continued)

* NMNH = National Museum of Natural History, Washington, D.C.; ANSP = Academy of Natural Sciences, Philadelphia; MCZ = Museum of Comparative Zoology, Harvard University; LACM = Los Angeles County Museum; AMNH = American Museum of Natural History, New York; FMNH = Field Museum of Natural History, Chicago, Ill.; BPBM = Bernice P. Bishop Museum, Honolulu, Hawaii; DMNH = Delaware Museum of Natural History; CAS = California Academy of Sciences.

Table 8-3 (Concluded)

Institution	Catalogued Units (x 1000)	Uncatalogued Units (x 1000)	Estimated Total (x 1000)
	Smaller Institutions*		
NCM	80	11	2,600
SDNH	76	10	350
INHS	75	2	?
OSU	55	35	1,400
UF	40	55	1,500
UINH	32	0.2	250
UCM	30	3	600
UAT	22	1	125
MPM	20	0.8	160
WSM	13.6	1	25
UM	13	7.5	54
EKU	11.4	0.25	432
UNC	10	2	100
DM	8.6	2	52
CMC	?	?	43
UTEP	7.8	1.5	?

* NCM = National Museum of Canada; SDNH = San Diego Natural History Museum; INHS = Illinois Natural History Survey; OSU = Ohio State University; UF = Florida State University Museum; UINH = University of Illinois Natural History Museum; UCM = University of Colorado Museum; UAT = University of Arizona at Tucson; MPM = Milwaukee Public Museum; WSM = Washington State Museum; UM = Rosenteil School of Marine and Atmospheric Sciences, University of Miami; EKU = Eastern Kentucky University; UNC = Institute of Marine Sciences, University of North Carolina; DM = Dallas Museum of Natural History; CMC = Charleston Museum, Charleston; UTEP = University of Texas at El Paso.

Table 8-4

Major Identification Guides Dealing With

Freshwater Mollusks (Unionidae)

Reference	Address	Cost
American Malacological Union "How to Collect and Study Shells	Department of Malacology, Academy of Natural Sciences, 19th and the Parkway, Philadelphia, PA 14103	$ 2.50
Baker, F. C. 1928. Freshwater Mollusca of Wisconsin. Vols 1 and 2. Wisconsin Academy of Sciences, Arts and Letters	Out-of print but frequently available from dealers in used books.	Variable; probably about 40.00
Buchanan, A. C. 1980. "Mussels of the Meramec River Basin, Missouri," Aquatic Series 17, Jefferson City, MO	Missouri Department of Conservation, Box 180, Jefferson City, MO 65102	No charge
Burch, J. B. 1975. Freshwater Unionacean Clams (Mollusca: Pelecypoda) of North America, Malacological Publications, Hamburg, MI, pp 1-204	Malacological Publica- Box 193, Hamburg, MI 48139	16.50
Burch, J. B. and C. M. Patterson. 1976. "Key to the Freshwater Pelecypods (Mussels and Clams) of Michigan," 35 pp	Museum of Zoology University of Michigan Ann Arbor, MI 48109	1.25
Clarke, A. H., Jr. 1973. "The Freshwater Molluscs of the Canadian Interior Basin," Malacologia, Vol 13, pp 1-509	Department of Mollusks Academy of Natural Sciences, 19th and the Parkway, Philadelphia, PA 19103	about 25.00
Clarke, A. H., Jr. 1981. The Freshwater Molluscs of Canada, Special Publication, National Museum of Natural History, Ottawa, Canada	Publications Division, National Museums of Canada, Ottawa, Canada K1A0M8 or University of Chicago Press, Chicago, Illinois	40.00

(Continued)

Table 8-4 (Continued)

Reference	Address	Cost
Fuller, S. L. H. 1980. "Freshwater Mussels (Mollusca: Bivalvia: Unionidae) of the Upper Mississippi River: Observations at Selected Sites Within the 9-ft Navigation Channel Project for the St. Paul District, U. S. Army Corps of Engineers, 1977-1979," Vol I, Report No. 79-24F, Academy of Natural Sciences of Philadelphia	Librarian, Division of Limnology and Ecology, Academy of Natural Sciences, 19th and the Parkway, Philadelphia, PA 19103	No charge
Johnson, R. I. 1970. The Systematics and Zoogeography of the Unionidae (Mollusca: Bivalvia) of Peninsular Florida, Harvard University, Cambridge, MA	Department of Mollusks, Museum of Comparative Zoology, Harvard University, Cambridge, MA 02138	$ 10.30
Johnson, R. I. "The Unionidae (Mollusca: Bivalvia) of Peninsula Florida." Harvard University, Cambridge, MA	Department of Mollusks, Museum of Comparative Zoology, Harvard University, Cambridge, MA 02138	2.50
La Rocque, A. 1976. "Pleistocene Mollusca of Ohio." Ohio Department of Recreation and Natural Resources, Columbus, Bulletin 62, pp 1-4	Ohio Geological Survey, Fountain Square, Bldg B, Columbus, OH 43224	12.00 (4 vols)
Mathiak, H. A. 1979. A River Survey of the Unionid Mussels of Wisconsin 1973-1977. Sand Shell Press, Horicon, WI, pp 1-75	Sand Shell Press Box 44, Horicon WI 53032	15.00
Murray, H. D., and A. B. Leonard. 1962. Handbook of Unionid Mussels in Kansas, University of Kansas, Museum of Natural History, Miscellaneous Publication No. 28, 184 pp.	Museum of Natural History, University of Kansas, Lawrence, KS 66044	5.50

(Continued)

Table 8-4 (Concluded)

Reference	Address	Cost
Ortmann, A. E. 1919. "A Monograph of the Naiades of Pennsylvania, Part III. Systematic Account of the Genera and Species." Memoirs of the Carnegie Museum 8 (1919-1921), pp 1-384	Carnegie Museum of Natural History, 4400 Forbes Ave., Pittsburgh, PA 15312	$5.00
Parmalee, P. W. 1967. "The Freshwater Mussels of Illinois." Illinois State Museum, Popular Science Series, Vol 8, 108 pp.	Illinois State Museum Spring & Edwards Streets Springfield, IL 62701	2.50
Starrett, W. C. 1971. "A Survey of the Mussels (Unionidae) of the Illinois River: A Polluted Stream," Illinois Natural History Survey Bulletin Vol 30(5), pp 266-403	Chief, Illinois Natural History Survey Natural Resources Bldg. Urbana, IL 61801	No charge
Walker B. 1928. "The Terrestrial Shell-Bearing Mollusca of Arkansas," Miscellaneous Publication, University of Michigan, 180 pp	Museum of Zoology University of Michigan Ann Arbor, MI 48109	6.50

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Morrison, J. P. E. 1969. "The Earliest Names for North American Naiads," Bulletin of the American Malacological Union for 1969, pp 22-23.

Murray, H. D., and Leonard, A. B. 1962. Handbook of Unionid Mussels in Kansas, University of Kansas, Museum of Natural History, Miscellaneous Publication No. 28, 184 pp.

Parmalee, P. W. 1967. "The Freshwater Mussels of Illinois," Illinois State Museum, Popular Science Series, Vol 8, 108 pp.

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PART IX: RELOCATING MUSSELS

Introduction

146. There are occasions when it is necessary to remove mussels from their native habitat and keep them alive for short periods of time under artificial conditions. This should be considered if unknown specimens are collected which need to be identified or verified by an expert. In this case the individuals in question can be held in an aquarium until they are identified, or alternatively, sent by mail to someone who is knowledgeable on unionid taxonomy. On a larger scale, entire populations have been removed from areas about to be affected by some outside activity and transplanted to a new site. For example, in 1977 on the upper Mississippi River three Lampsilis higginsi and 16 Cumberlandia monodonta were moved 1 mile upriver of an area where a bridge was to be demolished. The Tennessee Valley Authority (TVA) is now completing the planning of a large-scale program to move the bird-wing mussel (Conradilla caelata); up to 1000 individuals of this species will be taken from locations to be impacted by the Columbia Dam Project on the Duck River and moved elsewhere where suitable habitat exists. To date, WES is unaware of any long-term study following mussel relocation and recommends that a Government or other agency conduct such a study to determine the success of this work.

147. This Part contains information on how to keep mussels alive under artificial conditions for the purposes of identification or transfer to another location. Part X contains brief synopses of objectives, methods, and short-term results of some of these large-scale projects involving transfer of mussels from one area to another.

Biological Background

148. There are certain aspects of bivalve anatomy and behavior which must be considered when dealing with live specimens. As adults these organisms have very low mobility, although some species are more

mobile than others. Adult locomotion is accomplished by extending the muscular foot out of the shell and into the sediments and then expanding it at the end to secure a tight hold. When the muscle contracts, the shell is moved through the substrate towards the point of temporary attachment. In the immature or glochidial stage, most freshwater mussels are obligate parasites on a particular species of fish. This characteristic provides the mussels a means for dispersal which is, of course, wholly dependent on the habits of the host species.

149. For the most part, unionids are fairly specific in their habitat requirements. There are species which are usually found in either lentic or lotic waters, and those which seem to prefer sand, mud, or gravel substrate. However, because of their poorly developed locomotory powers and their methods of dispersal in the parasitic (glochidial) stage, it is often possible to find some species living in habitats typically considered unsuitable.

150. Freshwater mussels are filter feeders: they obtain food by removing organic matter and microorganisms from the water. Since they are basically nonmotile, they cannot move long distances to feed. This does not discount reports that in the spring mussels move about vigorously seeking better substrate or currents rich in food materials. However, in general they are dependent upon circulating water to bring in food and dissolved oxygen and to remove waste products. Water currents help to move sperm from the male to the female who takes them in by way of the incurrent syphon. Brief periods of desiccation or adverse water quality may not be detrimental to freshwater mussels; they can survive short periods of toxic or poorly oxygenated water by closing their valves. Once conditions improve, the mussels reopen their valves and continue taking in water for food and dissolved oxygen.

Maintaining Mussels in Aquaria

151. It is not difficult to keep freshwater mussels alive in small aquaria. WES has kept common species alive for months in 10- and 20-gal aquaria with gravel or gravel/sand substrate. For the best chances of

success, natural conditions of water and substrate should be duplicated to the extent possible. However, the use of organically rich muck should be avoided since in closed systems it can cause conditions of low water quality and "blooms" of bacteria or sludge worms. A small air pump attached to an air stone will provide oxygen and water circulation. A small circulating water pump can also be used to aerate and mix the water, although this is not necessary. Since these organisms are filter feeders, sufficient algae should be periodically introduced and allowed to grow in the water; elaborate filtration systems which remove this food should be avoided. In certain areas mussels have been found living so close together that their shells practically touch. While they do survive under such conditions in nature, it is not wise to have such large numbers in a closed system. Try to allow at least 3 or 4 in. between specimens when keeping mussels in an aquarium. More information on maintaining mollusks under artificial conditions can be found in Fikes (1972), Bovjerg (1957), Badman and Chin (1973), and Churchill and Lewis (1924).

Food cultures

152. Separate culture tanks for food can be set up if mussels are to be held for more than a few days in aquaria. This is done by simply filling a glass or plastic container with clean water and setting it near a window or, if conditions permit, outside. To the container several litres or more of nutrient-rich water from a pond or the protected area of a lake which contains algae and other organisms should be added. A few handfuls of dry straw, hay, or leaves will provide nutrients, organic matter, and substrate for attachment needed for many species of algae and other organisms. If the water becomes too nutrient-rich after a while, simply pour off half or more of the contents of the container and refill with clean water.

153. Add a litre or more each day of the culture water, which will contain algae, bacteria, and detritus, to the aquarium containing mussels. The growth of algae and perhaps of bacteria on the glass can be controlled by scraping the sides of the aquarium regularly with a razor

blade or small nylon pad. Snails also clean algae from the sides of aquarium glass.

Changes in water temperature

154. Freshwater mussels, like most organisms, are adversely affected by abrupt changes in water temperature. A change from cool to warm usually is more harmful than the reverse condition. Care should be taken that adequate time is allowed for the mussels to acclimate to the temperature of their new surroundings. The thinner shelled species (Anodonta spp. and Leptodea spp.) appear to be most susceptible to changes in water temperature.

Maintaining Mussels in Their Natural Habitat

155. Instead of bringing them inside, it is possible to keep mussels in a semicontrolled condition in or very near their natural habitat. Small portable retaining structures can be built from four stakes and hardware cloth. Alternatively, 5-gal plastic buckets with bottoms removed and 1/2-in. holes cut in the sides, as well as metal or plastic milk crates or any suitable device, will perform the same function. It is important that the mussels have access to the natural substrate and currents and are still protected from predators such as raccoons or muskrats. The sides of the container should extend deeply enough into the substrate (at least 10 cm) so that the organisms cannot escape by burrowing. More information on temporary retaining structures can be found in Kaskie (1971).

Relocating Mussels

156. There are often occasions when it may be advantageous to remove mussels from their native habitat and transplant them to another site. This should be considered if their present site is about to become uninhabitable because of modifications to the waterbody or adverse impacts caused by navigation traffic, bridge relocations, or presence of toxic or thermal effluents. Additionally, one or several

live mussels may have to be taken from the area and sent or carried to an expert for identification. The following describes the necessary steps required when relocating mussels. This information has been developed from recommendations by Fuller (1980), a discussion of relocating mussels in the upper Mississippi River (Oblad 1979), plans developed by the Tennessee Valley Authority to relocate Conradilla caelata (Jenkinson 1981), and ongoing studies at the WES.

157. Of primary importance is locating a suitable site for the transplanted organisms. This should be free of future disturbances; i.e., not likely to be affected by predation, navigation traffic, or commercial sampling. The site should have good access and be easily located by subsequent workers.

158. After a suitable site has been found, the specimens must be carefully removed from their present habitat. This is best done by hand, either by hiring professional divers, or by wading, or using snorkel gear. Since the objective is to remove as many specimens as possible, collecting devices such as brails, dipnet dredges, and rakes are not appropriate. In addition, many of these samplers (especially the dipnet dredge) are potentially destructive to the mollusks. If the area is too large to completely sample with the device, a decision will have to be made to limit either the total number or variety of organisms taken.

159. After the organisms have been retrieved, they must be protected from desiccation until they can be relocated. Mussels can be stored for quite a while simply by keeping them moist and cool. If large tanks with clean, well-aerated water and stable substrate are not available, there are other ways to safely hold mussels. WES personnel have kept common species (the washboard, Megalonais gigantea; three ridge, Amblema costata; three-horn Obliquaria reflexa; floater, Anodonta grandis; and pigtoe, Fusconaia flava) alive for 5 days by simply wrapping them in moist burlap and storing them in a cooler (65-80°F). Jones (1950) was able to keep specimens alive for 30 days by wrapping them in moist cheesecloth. The cheesecloth or burlap keeps the mussels wet and cool and prevents damage to the shells if they are handled roughly.

160. After the mussels have been safely collected and transported to their new site, it is important that they are carefully placed into the substrate. Do not simply toss the specimens into the water since mortality often results if mussels are unable to implant themselves into the substrate (Imlay 1972). If mussels are continually buffetted and rolled about by turbulent water, they do not open their valves and can eventually asphyxiate or starve. When positioning specimens, place the anterior end (the swollen portion with the umbones) directly into the substrate. Establish the organisms at the depth at which they were found in the previous areas. The opening between valves should be oriented upstream or into the current. If it is possible to sex the individuals, attempt to place the males upriver from the females to help ensure that females are able to take in sperm if and when it is produced.

Mussel Shipment

161. There may be situations when it is necessary to ship small numbers of unknown live mussels long distances by mail to an expert for identification. The specimens can be identified then returned to the sender for replacement in their native habitat. In 1980, representatives from the U. S. Army Engineer District, Rock Island, shipped by air a single live specimen, approximately 6 mm long, suspected of being Lampsilis higginsi, to Dr. David H. Stansbery, Ohio State University, for identification. The juvenile specimen, which turned out to be not endangered, was successfully received by Dr. Stansbery. It should be noted that juveniles in this size class are particularly difficult to identify.

162. The best container for shipping live organisms is a 275-lb test, double-wall, corrugated, weather-resistant styrofoam box. Alternatively, any sturdy, watertight container will suffice. The box must be securely wrapped, with a description of contents (endangered species), and the return address clearly marked. To speed the arrival, priority mail should be used and the package hand-carried to the post

office. The receiving party should be notified of the approximate arrival date. Express mail, commercial air freight, and 24-hr delivery service, if available, should be considered. Additional information on shipping unusual items can be obtained by consulting "Acceptance of Hazardous or Perishable Articles," Publication No. 52 of the U. S. Postal Service.

163. Before the organisms are placed into the box, they should be individually wrapped in moist (not wet) burlap or cheesecloth. Mr. Tom Freitag, U. S. Army Engineer District, Detroit, shipped a specimen in long strands of sphagnum (not commercial peat), placed in a plastic bag with holes. The bag was placed in a box with some openings to allow for adequate ventilation. Specimens should be packed so they will not rattle about if the box is roughly handled or turned upside down. Styrofoam beads around a plastic bag allow for air passage and secure the specimen from damage. If air temperatures are much above 80°F, a small quantity of ice or bottled coolant (blue ice) should be used. Take precautions to ensure that when the ice melts the organisms will not be immersed in the water. Clean, dry sand or other absorbent material (not newspaper, which contains sulfides and other impurities) can be packed at the base and sides to absorb extra moisture.

164. To test the success of mailing mussels, six separate shipments of live organisms were sent from Vicksburg, Mississippi, to Bloomsburg, Pennsylvania, a distance of about 1000 miles (Table 8-1). A total of 51 individuals were sent; of these, 11 did not survive. Six of the 11 species which did not survive were thin-shelled Anodonta spp. (none were crushed). Total elapsed time, which appeared unrelated to mortality, ranged from 46-1/2 to 86 hr. While the majority of the individuals survived this treatment, it is obvious that extremely rare or valuable live specimens should probably not be shipped great distances. In the fall of 1981, WES sent live mussels successfully to San Francisco by air. They were packed in a plastic 5-gal bucket with 2-3 in. of moist sand on the bottom. About 30 specimens (Corbicula and Plectomerus dombeyanus) were carefully layered over the sand. Moist brown paper and

plastic were placed on top of the mussels. All were received in San Francisco within 12 hrs and were alive.

Marking Shells

165. If newly replaced specimens are to be collected and recognized at a later time, some method of uniquely marking each individual will be necessary. Oblad (1979) and Isley (1914) describe the use of identifying tags which are secured to each shell. A 1/16-in. hole must first be drilled between the outer margin and the pallial line of one of the valves. This is accomplished by gently separating the shells with a speculum or modified O-ring pliers (see Part II), temporarily detaching the mantel from the shell margin, and drilling through the shell only. The tag can then be secured to a loop of monofilament line and threaded through the hole.

166. Another useful technique is to paint identifying numbers with latex paint on individual specimens. Epoxy, which is resistant to wear and chemicals, has also been used; this is an easier and more rapid technique than the previously described method. However, the paints can only be applied when the shells are dry. Care must be taken so that mortality does not occur as a result of specimens being held out of water for too long a period of time. Oblad (1979) described the use of fluoresent paint to mark live specimens; this had not worn off the shells after one year in the water.

167. Probably the easiest and safest shell-marking method is to engrave a number on the exterior of the shell using a portable grinding tool or metal etcher. This can be done with specimens wet or dry and with the valves completely closed.

168. Thoma et al. (1959) reviewed several methods of marking shells and recommended a code system using holes drilled into the shell. This process did not damage the shells and produced permanent marks which are not obvious to the casual collector.

Summary

169. It is fairly easy to safely capture, hold, permanently mark, and transport mussels and replace them into a suitable habitat. If an unusual or endangered population exists in an area about to be altered by construction or maintenance work, mussels can be transplanted to another area if they cannot be protected or maintained in their existing surroundings. Under some conditions it is necessary to send unidentified specimens by mail or other carrier to a taxonomist some distance away. Although some mortality can occur, usually good results are achieved. If there is a very good chance that the specimens in question are endangered and long distances are involved, it is best not to send them through the mail. A private 24-hour courier agency should also be considered if it is necessary to move mussels rapidly.

Table 9-1

Summary of Shipment of Mussels Mailed to Bloomsburg, Pennsylvania, From Vicksburg, Mississippi, October-November, 1981

Item Description	Contents	Mortality
Two coolers, no ice: priority-mailed 26 Oct 81, time 1500; received 28 Oct 81, time 1600; placed in aquarium 29 Oct 81, time 0830; total elapsed time, 65-1/2 hr	4 *Amblema plicata*	1
	2 *Fusconaia flava*	none
	1 *Fusconaia ebena*	none
	2 *Tritogonia verrucosa*	none
	1 *Obliquaria reflexa*	none
	1 *Anodonta grandis*	1
	2 *Leptodea fragilis*	none
	1 *Quadrula quadrula*	none
	3 *Plectomerus dombeyanus*	none
	3 *Lampsilis teres*	none
One cooler, no ice: priority-mailed 26 Oct 81, time 1500; received 30 Oct 81, time 1400; placed in aquarium 30 Oct 81, time 1500; total elapsed time, 86 hr	1 *Quadrula quadrula*	none
	6 *Lampsilis teres*	none
	3 *Plectomerus dombeyanus*	none
	1 *Corbicula fluminea*	none
Three coolers, with ice: priority-mailed 21 Nov 81, time 1530; received 23 Nov 81, time 1300; total elapsed time, 46-1/2 hr	20 *Megalonais gigantea*	3
	5 *Anodonta grandis*	3
	1 *Anodonta suborbiculata*	1
	2 *Quadrula pustulosa*	none
	1 *Fusconaia undata*	1

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X: LARGE-SCALE PROJECTS ON RELOCATING MUSSELS

Introduction

170. There are times when a planned maintenance or construction activity on a waterway will detrimentally affect endangered species. Often these projects can be modified in such a fashion that mussels (or other significant organisms) are not injured. If the project cannot be modified, it may be more realistic to move certain valuable organisms to a more suitable site. Such an action does not preserve habitat, a rapidly dwindling resource, but it does protect uncommon or endangered species which might otherwise be lost. The following discussion provides salient information on some of the completed and current projects on relocation. In Part XI, alternatives to moving mussels--i.e., protecting or maintaining them in their natural areas--are described. Part XII describes techniques for the creation of habitat for freshwater mussels.

Relocating Lampsilis higginsi in the Upper Mississippi River

171. In 1977, representatives of Ecology Consultants, Inc., collected a single specimen of the federally endangered mussel, Lampsilis higginsi, from Sylvan Slough in the upper Mississippi River near Moline, Illinois. The work was done as part of a pilot survey requested by the U. S. Army Engineer District, Omaha. The purpose of this work was to assess probable impacts of plans to construct a new bridge at Moline, Illinois, about 50 ft downriver from the old bridge. As a result of this find, the NUS Corporation, Pittsburgh, Pennsylvania, eventually received a contract to collect and transplant endangered mussels from the area to a new site away from any construction impacts (Oblad 1979).

172. The exact area from which the specimens were to be removed was identified using triangulation and then marked with blocks, ropes, and buoys. Divers equipped with SCUBA searched each of two 40- by 70-ft sites, collected all living mussels, and placed them in a 12- by 14- by

30-in. container made of 1-1/2- to 2-in. mesh. From the two sites, a total of 7096 specimens representing 25 species was brought to the surface. The most common types were the giant washboard, Megalonais gigantea (5600), three ridge Amblema plicata (551), the pink heelsplitter Proptera alata (325), and the pimpleback Quadrula pustulosa (170). Three Lampsilis higginsi (endangered) and 16 Cumberlandia monodonta (very uncommon) were also collected. These latter two species were marked with plastic tags attached to monofilament line and threaded through a small hole near the outside margin of the shell (for more details on tagging mussels see Part IX). In addition, about 50 specimens of M. gigantea and A. costata were sprayed with fluorescent paint. The federally listed endangered L. higginsi, the uncommon C. monodonta, and the two groupings of M. gigantea and A. plicata were then replaced by hand at a new site upriver of the bridge relocation. All specimens were handled by divers who gently placed them along a line anchored with blocks and set parallel to the current. The specimens marked with a tag were positioned so that the identification tag did not flutter obviously in the current but remained buried in the substrate.

173. Approximately 1 year later on 8 September 1979, the relocation team returned to the area. All three L. higginsi and 11 of the 16 C. monodonta were located. Thirty of the 50 M. gigantea and 10 of the 50 A. plicata were also found. All relocated mussels were alive and appeared to be in good conditon. No dead tagged or marked individuals were observed.

174. It was concluded that the relocation of mussels was a success. A high percentage of the transplanted specimens were found, and all of these were in good condition. As demonstrated by this work in the upper Mississippi River, relocation of common and uncommon mussels is not difficult and can yield positive results. In the event that modification of waterways could detrimentally affect mussels, relocation of the species of concern is a realistic and viable alternative.

Cumberlandian Recovery Program

175. In the 1960's the Tennessee Valley Authority (TVA) began to study the feasibility of placing a series of reservoirs on the Duck River in central Tennessee. In 1968 the first reservoir, a 3230-acre impoundment in the headwaters at Normandy, Tennessee, was finished. A 12,600-acre impoundment in the middle length of the river at Columbia, Tennessee, was started in 1973 but then halted in 1977. Work was stopped by actions of the U. S. Fish and Wildlife Service who issued a biological opinion which stated that completion of the Columbia Dam would jeopardize the continued existence of two mussel species: the bird wing pearly mussel Conradilla caelata (Conrad, 1834) and the Cumberland monkey face pearly mussel Quadrula intermedia (Conrad, 1836).

176. The Duck River has long been known to support a diverse and unique assemblage of mussels; Ortmann 1924 recognized 45 species or forms from the Duck River which he defined as Cumberlandian in origin. This Cumberlandian fauna was restricted to the upper and middle reaches of the Duck and Tennessee River Systems and could be contrasted with at least two other species groups. The first he termed Ohioan because it was located in the Ohio-Mississippi Drainage; the other group, of undetermined origin, was found in all major streams including those containing Cumberlandian and Mississippian fauna. Thirteen of the 25 federally-listed mussels species are Cumberlandian. Of these, seven have been recorded from the upper Duck River. The Duck River distribution of the two previously mentioned species, C. caelata and Q. intermedia, lies entirely within the 54-mile stretch of river which was to be impounded by the Columbia Dam. Both species also occur, very rarely, in other rivers.

177. TVA concluded that any alternatives to the project as planned would not be acceptable. They did, however, propose a conservation program to be implemented for the endangered species as well as for the rest of the Cumberlandian fauna to be affected by the Columbia Dam project. The suggested conservation plan, which included proposals to relocate the mussels, was acceptable to the U. S. Fish and Wildlife

Service under the stipulation that the conservation program be satisfactorily executed before the reservoir project could be completed.

178. The proposed conservation program consisted of two phases. The first was designed to accumulate information on the present distribution, life history, and ecological requirements of the Cumberlandian mussel fauna. In addition, specific habitat information was gathered on a number of possible transplant sites in the unaffected portions of the river. The second phase was intended to use the information gathered to enhance populations and communities of the Cumberlandian species whenever they occur in the Tennessee River System. It was planned that this be accomplished by studies on artificial propagation and natural history and the development of a procedure to transplant the mussels to the new area. The program objectives were to be satisfied with completion of the following nine tasks:

a. Mollusk surveys.
b. Potential fish host surveys.
c. Fish host identification.
d. Development of artificial culture media.
e. Physical habitat analysis.
f. Limnological analysis.
g. Plant and plankton analysis.
h. Microfauna analysis.
i. Transplant site selection.

179. The bird wing mussel C. conradilla is unique because, although not widely distributed, it is usually very abundant where found. In the 54-mile reach of the river to be affected by the project, it has been estimated that there are about 20,000 individuals of this species.

180. The bird wing pearly mussel has not been found in the Duck River outside of the area of the Columbia Dam. It has been collected in only one other river (the Clinch River) in the United States. Current plans call for collecting about 1,000 of this species and moving them to protected areas out of the impact area. Candidate streams included free-flowing portions of the Duck, Buffalo, Powell, Clinch,

North Fork Holston, Flint, Paint Rock Rivers and possibly other valley rivers and streams. Potential transplant sites were to be restricted to tributaries of the Duck and Tennessee Rivers above Muscle Shoals, Alabama. The initial list was to include streams unaffected by man's activities and in drainage areas larger than 150 sq miles. The final relocation sites were to be identified based upon the presence or absence of critical factors which included stream morphology, substrate types, and presence of suitable host fish. Based upon the habitat data collected throughout the range of the extant populations of these endangered species, a hypothetical profile of an ideal transplant site was developed.

181. Final selection of the transplant sites was made in the fall of 1982. During the actual relocation, specimens were removed by hand, using divers equipped with SCUBA and snorkel gear. The mussels were held briefly in coolers or tanks, then quickly transported by truck to new sites. Specimens were marked and replaced at specific sites by hand. Monitoring of the newly placed population will be conducted at least twice a year. For more information on this project, contact Mr. John Jenkinson, TVA, Knoxville, Tennessee, and see Jenkinson (1981) and Tennessee Valley Authority (1979, 1980).

182. For information on the artificial propagation of mollusks, contact Mr. B. G. Isom, TVA, Muscle Shoals, Alabama. During the summer of 1981 Isom redeveloped the technique first described by Ellis (1929) and Ellis and Ellis (1926), of rearing mussels without a fish host. He prepared a nutrient solution composed of various amino acids and fish blood as a growth medium for juvenile mussels, a technique which could provide great numbers of uncommon or endangered species as well as common mussels for commercial (jewelry) purposes.

A Proposed Contingency Plan for Lampsilis higginsi in the Upper Mississippi River

183. It has recently come to the attention of malacologists that the Higgins' eye mussel (Lampsilis higginsi) is more common in the upper Mississippi River than was once believed. When the east channel of the

Mississippi River at Prairie du Chien (river miles 635.3 to 636.3) was dredged in 1976, 14 of the 1600 live specimens found on the dredged material were L. higginsi (Havlik and Stansbery 1978). For a more complete discussion of the Higgins' eye mussel in the upper Mississippi River, see Fuller (1980) and Nelson and Freitag (1979).

184. Consideration of impacts to the extant populations of L. higginsi has been the subject of concern of personnel at the U. S. Army Engineer District, St. Paul. The most recent problem arose as a result of discovering structural defects in the Highway 18 bridge between Wisconsin and Iowa. If it became necessary to close this bridge during the shipping season, another navigation route away from the damaged bridge would have to be chosen. It was determined that development of an alternative route would require dredging an area about 3.75 miles long, with a width varying from 200 to 400 ft. Based upon a Wisconsin Department of Natural Resources survey, it was estimated that 20,000,000 live mussels inhabited this area. In addition, it was believed that as many as 100,000 of these were L. higginsi.

185. A contingency plan was developed by the St. Paul District which addressed possible methods for removing and relocating the Higgins' eye mussels. Collecting the mussels with a brail was determined to be inefficient; the use of SCUBA divers would be time-consuming and prohibitively expensive. It was decided that the hydraulic (jet) dredge, which is used primarily for the commercial harvest of marine hardshell clams, would be the most useful. This equipment is towed on a cable from a boat, while a cutterbar loosens the substrate 5 to 6 in. below the surface. Pressurized water from a series of nozzles is directed towards the substrate to further loosen the material, and a steel mesh net picks up the shellfish. This harvester collects in a swath of 60 in. or more, can move up to 3 knots, and usually does not kill the mussels.

186. The plan was to use the hydraulic dredge to collect all live mussels; then the catch would be brought onboard to sort out the Higgins' eye mussels. The endangered mussels would be sexed, aged, and marked and then placed in plastic milk containers and stacked in a

flow-through tank filled with river water. The live organisms would be transplanted to an appropriate site where a team of divers would carefully replace each specimen into the substrate.

187. After further investigation it was decided that the dredge would not work in the uneven bottom of the Mississippi River. Furthermore, since the bridge was made safe prior to the navigation season, the contingency plan was never attempted. However, the proposed plan is feasible and could be adapted to other areas if needed. For more information contact Mr. Robert Whiting, U. S. Army Engineer District, St. Paul.

Popular Accounts

188. Commercial shell fishermen often describe experiences moving mussels from one area to another. During the 1979 symposium of the Upper Mississippi River Conservation Committee on Upper Mississippi River Bivalves (Rasmussen 1980), Truman Wilson, then of Kankakee, Illinois, recounted a time when he had moved about 15,000 pounds of live mussels to a river where there were no large beds. In their new habitat the mussels evidently thrived and reproduced naturally.

189. A commercial shell buyer in Savannah, Tennessee, described an experience he had had in September 1981 with relocating mussels. Over a period of years he had moved quite a number to an area in the Tennessee River in an attempt to establish a commercial-quality bed. The mussels became established in the new area; however, the bed was eventually found and harvested by other commercial fishermen.

190. These accounts indicate that under some conditions it can be fairly easy to establish mussels in new areas. Under certain conditions, many of the precautions described in Part IX need not be followed to achieve success.

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PART XI: ALTERNATIVES TO RELOCATING MUSSELS

Introduction

191. The purpose of this Part is to present alternatives to transplanting mussels from one area to another. Relocating these organisms (Parts IX and X) should be considered only if existing habitat is likely to become totally unsuitable because of a known future environmental perturbation. In addition, before large-scale movement of mussels is considered, it is wise to determine whether or not the existing habitat can support these species. This Part will discuss the sensitivity of mussels to various chemical and physical conditions, and techniques for identification and protection of particular areas for these organisms.

Sensitivity of Mussels to Environmental Perturbations

192. Table 11-1, developed from Fuller (1974) and other authors, presents a list of chemical parameters and reported toxic levels for freshwater mussels. The mollusca are unique in that while they are sensitive to turbidity, potassium, low dissolved oxygen, and other adverse conditions, most species can, by clamping their valves together, withstand short periods of poor water quality. The thick-shelled heavy species (Quadrula sp., Amblema sp.) are able to seal their shells and are more tolerant than the thin-shelled species such as those belonging to genera Anodonta and Leptodea. In addition, WES has noted that the latter two genera are usually the first to succumb to rough handling, temperature shock, etc., that occur sometimes under laboratory conditions. Presumably this is why the thin-shelled species are less common in rivers which experience turbulent flow, turbid water, and frequent periods of fluctuating water level.

Identification of Unique Areas

193. It has been WES's experience that it is possible to identify and set aside sites at most water resource projects for the protection of certain organisms. Many times these existing sites can be identified during early planning stages; alternatively, a project can be modified to allow protection or creation of unique areas. In the Tennessee-Tombigbee Waterway (TTW), the U. S. Army Engineer District, Mobile, has proposed setting aside a site for mussels and other bottom dwelling organisms near Columbus, Mississippi. This habitat, to be located in an abandoned bendway below the Columbus Lock and Dam (see Part XII), has not been constructed yet, and as of the summer of 1982 is still in planning stages. In addition to the bendway near Columbus, there are many other sites along the TTW which could support mussels. Any area which experiences fairly high flow could be potentially suitable. Sites below run-of-the-river reservoirs or minimum-flow release structures can support viable mussel fauna and other organisms which require running water.

194. In an entirely different type of water resource project, the Green River Dam in Kentucky, Kessler and Miller (1978) described a population of floaters (Anodonta grandis) along the front of Green River Lake, which is a man-made waterbody located in south-central Kentucky. Evidently a fish carrying viable glochidia was present at the time of dam closure. A fairly extensive population of these mussels was found successfully inhabiting riprapped areas along the face of dam in about 5 to 10 m of water. At the time of this discovery, only similarly aged specimens were taken. It is not known whether or not this is a reproducing population.

195. Many workers* have identified large and diverse mussel beds downriver of lock and dam structures in medium-sized to large rivers.

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* John Jenkinson, Tennessee Valley Authority, Knoxville, Tenn.; John Kessler, U. S. Army Engineer District, Louisville, Louisville, Ky; Arthur Clarke, ECOSEARCH, Inc., 7 Hawthorne St., Mattapoisett, Mass.

In the Green River in Kentucky, WES has also noted many dense populations of mussels below dams. It is unclear whether these exist because of dams or whether dams were placed in areas in which these organisms were living. It is known, however, that these areas contain adequate flow of highly oxygenated water necessary for these fairly nonmotile organisms. In addition, host fish are usually numerous in these areas, feeding in many cases on plankton and aquatic insects in the impounded water. Usually areas below dams are rich in particulate organic matter and algae which are important food items for these species. Finally, WES has noted that many fishermen use parts of mussels as bait; it is not uncommon for these people to empty a bucket into the water at the end of a day's fishing.

196. Fuller (1978), in a survey of the upper Mississippi River mussel populations, found mussels living in association with wing dams. Particularly, the spectacle case (Cumberlandia monodonta) was found inhabiting crevices between riprap along wing dams. This particular species is rarely taken in the river proper, but appears to prefer crevices in and between large rocks. In the Clinch River it also occurs in mud along the bank below riffles.

197. James L. Peach (1982), President of the American Shell Company in Knoxville, Tennessee, described large, commercially valuable mussels in impounded reservoirs and lakes. It was his opinion that the man-made waterbodies have improved the quality of the commercial catch of mussels in this country. This view is also held by Isom (1971), Tennessee Valley Authority, who cited cases of commercially valuable shells taken from "overbank areas" in the Tennessee River.

198. In the planning stages of a project it is important to search for areas unaffected by navigation, heavy recreational use, or obvious sources of pollution. Substrate should be stable and consist of sand, gravel, or mud-gravel mixtures. Proximity to areas which attract fish, such as dikes, gravel bars, standing timber, and incoming and tributary streams, can also be valuable mussel habitat.

199. Under natural conditions mussels have unique distribution patterns which should be considered when establishing habitat for them.

The following should be kept in mind when planning habitats for mussels:

a. These organisms are typically found in water from 1 to 6 ft deep (Baker 1928). This is important when evaluating results of pollution or other baseline surveys or when setting aside an area for mussels. It should be obvious that very deep water, even if it contains adequate substrate and good water quality, may not be suitable for these organisms.

b. In most natural streams both unionid and gastropod species increase as one progresses from the headwaters to the mouth (Goodrich and van der Schalie 1944, Baker 1928). The relative absence of mussels in the upper reaches of streams may be a function of low or poor food quality, intermittent water levels, or a lack of fish hosts.

c. Most mussels require the presence of fish hosts to carry the immature or glochidial form. However, certain species, e.g., (Anodonta imbecillis), appear to develop successfully without hosts, or some may be able to utilize more than a single species of fish to carry glochidia. The research to ascertain the correct fish host is fraught with difficulties, and some earlier data concerning host mussel relationships may be incorrect.* For example, it is possible that fish may harbor glochidia of some mussels only under specific conditions or only the first year of development. Mr. B. G. Isom is currently perfecting a technique for rearing mussels without fish hosts. This procedure will make it possible to protect large numbers of common, uncommon, or endangered mussels. For more information on this promising technique for culturing valuable species of mussels, contact Mr. B. G. Isom, Tennessee Valley Authority, Muscle Shoals, Alabama. Fuller (1978) describes a situation with the ebony shell (Fusconaia ebena) which used to be common in the upper Mississippi River before closure in 1913 of a hydroelectric dam at Keokuk, Iowa. The dam closure greatly reduced from the upper reaches of the river an anadromous fish, the skipjack herring (Alosa chrysochloris), reportedly a primary host for two mussels, the ebony shell and the elephant ear (Elliptio crassidens). Both of these species are now extremely uncommon in the Mississippi River above the dam, even though there are rich and diverse beds containing other species above Keokuk.

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* Personal Communication, October, 1981, Mr. B. G. Isom, Biologist, Tennessee Valley Authority, Muscle Shoals, Ala.

d. In streams and rivers, shifting sand and gravel make otherwise high-quality habitat unsuitable for mussels and other benthic invertebrates. In certain parts of Mississippi, WES has visited streams where the water quality was excellent, yet mussels were few or in some cases absent because of the nature of the bottom material. Even wading in these areas was extremely difficult because the substrate was not firmly packed.

e. In general the thicker shelled species (Quadrula sp., Pleurobema sp., etc.) are found in running water with gravel or rock forming part of the substrate, while the thinner shelled species (Leptodea, Anodonta) are more common in slack or slowly moving water. However, because of mussels' passive modes of dispersal, one frequently collects shells in conditions which seem unsuitable. These organisms (while in general indicative of clean water) do not separate out into the various subgroupings based on specific water quality conditions as do some other aquatic invertebrates, notably the chironomids.

Protecting Existing Habitats

200. Man's activities can exert an observable effect on the freshwater unionid mollusks. The following are actions which can prove detrimental to these organisms:

a. Organic Enrichment. Organic enrichment, whether from surface runoff or point source effluents, is detrimental because of presence of settleable solids, toxic levels of certain elements and chemicals, and reduced oxygen levels. Some mollusks (including nonunionids) which appear to be tolerant of low levels of pollution are cited in Table 11-2. However, it is important to realize that low levels of pollution, which may cause fairly high growth of algae and certain types bacteria, can be beneficial to these organisms as long as food value in the water is increased, oxygen levels remain suitable, and concentrations of other toxic materials do not become excessively high.

b. Removal of Substrate. Alteration or removal of substrate in flowing water by dredging is detrimental to these invertebrates. Organisms can, of course, be directly removed and injured by a dredge. In addition, when substrate is removed mussels cannot survive very well on hard-packed clay or rocky material. If a mussel does not have good substrate in which to anchor, it will lie flat and cannot orient itself into the water current. In

addition, if it is not securely fastened it may roll about continually in the currents and starve to death since it cannot or will not feed.

c. Reservoir Construction. Fuller (1974) gives a very complete account of the effects of dams on mussel fauna of streams (see Table 11-3), although it is important to note that man-made and natural lakes do support mollusks (see Parmalee 1955). In addition, the quality of shells is often superior from a commercial standpoint in slow-water habitats. However, lakes typically support fewer species of mussels and other aquatic organisms than can a river, a much more diverse system. Flowing waters have a variety of depths, current speeds, light intensities, substrate types, and food supplies, plus a continuous flow of water to remove waste, flush away sediments, and bring in particulate matter. Stansbery (1976) lists 11 species belonging to the genus Dysnomia which are presumed to be extinct in the United States because of reservoir construction or channel maintenance activities in large rivers. For additional information on the effects of reservoir construction on mussels, see Bates (1962) and Stansbery (1970a, 1970b, 1970c, 1971a, 1971b, 1972a, 1972b, 1972c, 1972d, 1973a, 1973b). However, mussels do exist in reservoirs. Williams (1969) noted a preimpoundment bed of mussels in Kentucky Lake, Kentucky, that was living under 55 ft of water. Although these organisms were alive, he noted that glochidial infestations of fish were quite low. Probably the record depth for mussels was reported by Reigle (1967), who noted the floater (A. grandis) alive, although very stunted, at depths of 102 ft deep in Lake Michigan.

d. Low Dissolved Oxygen. Allen (1923) noticed that, under certain conditions of low oxygen tension, mussels (he did not state precisely which species was used) attempted to bring in more water than when adequate oxygen was present; they did this by opening their shells and siphons as widely as possible. When mussels pump great amounts of water, they are vulnerable to toxic waste.

Table 11-1

Ranges of Water Quality Parameters for Mussels

Variable	Effect on Mussels
Hardness	Found no mussels in central New York State in waters less than 46 mg/L of $CaCO_3$ hardness (Clarke and Berg 1959)
	Harman (1969) found some species at 21 mg/L of $CaCO_3$ hardness; generally, these organisms are found in waters with moderate levels of hardness
Alkalinity	According to Harman (1970) water should contain at least 15 mg/L of calcium carbonate
	According to Morrison (1932), Anodonta c. cataracta was found in waters containing 2.6 mg/L "fixed CO_2"
pH	Morrison (1932) found mussels living within a broad range of pH (5.6 to 8.3)
Arsenic	Sodium arsenic "hard water" was fatal to Amblema plicata in 3 to 16 days (Ellis 1936)
Cadmium	Solution of $CdCl_2$ above 0.001 mole inhibited the respiration of Anodonta cygnea (Lukasovics and Salanki 1968)
Chloride	Cvancara and Harrison (1965) recorded no mussels in the Turtle River, North Dakota, where chloride equaled or exceeded 87 mg/L. In the Green River, Kentucky, Amblema plicata and Megalonais gigantea withstood chloride better than other species of mussels (Williams 1969)
Copper	A maximum of 25 ppb of copper for several months was lethal to certain mussels (Imlay 1969)
Ammonia nitrogen	Starrett (1971) felt that ammonia nitrogen levels above 6.0 mg/L in the Illinois River restricted mussels because of the deleterious effect of this substance on host fish. However, Fuller (1974) points out that host fish were present and the ammonia nitrogen may have impacted mussels directly
Dissolved oxygen	Grantham (1969) found no mussels in Mississippi alive when dissolved oxygen dropped below 3.0 mg/L. Amblema plicata, which can close its valves tightly during adverse conditions, survived 10 weeks at 0 mg/L dissolved oxygen (Imlay 1971)
Silt	Ellis (1936) found that settled silt of 1/4-in. thickness was detrimental to most species of mussels if allowed to remain there for at least one week. However, if water currents flushed the substrate fairly soon after the settled material had been deposited, usually the mussels survived

Table 11-2

Mussels Tolerant of Extreme Environmental Conditions

Species	Type of Resistance
Uniomerus tetralasmus	Extremely tolerant of desiccation (Simpson 1892, Strecker 1908)
Anodonta imbecillis	Found in water with low dissolved oxygen (mean = 2.89 to 6.44 mg/L; number of samples = 21) (Wiebe 1928)
Amblema plicata, Lasmigona complanata	Most resistant to low water quality (Baker 1928)
Anodontoides ferussacianus	Found 1 ft below silt when dissolved oxygen was 6% of the stream water (Cole 1926)
Anodonta cataracta	Very resistant to low pH and total hardness less than 2.6 mg/L of $CaCO_3$ hardness (Morrison 1932)
Tritogonia verrucosa	Found in almost every type of stream habitat except shifting sand in large and small rivers (Murray and Leonard 1962)
Quadrula quadrula	Found in mud, sand, or gravel bottoms in medium to large rivers (Murray and Leonard 1962)
Leptodea laevissima	Found in large rivers on sand and in mud bottoms with good current (Baker 1928)
Proptera purpurata	Found in quiet pools with deep mud (Murray and Leonard 1962)

Table 11-3

Adverse Effects of Man's Activities on Mussels

Location	Problem	Cause	Author
Lake Keokuk (on the Mississippi River)	Loss of fish host	Weed clearing, construction of roads and riprap	Ellis 1931a
	Loss of *Lampsilis teres*	Sandbars had become covered with silt	Ellis 1931a
Bear Creek, Alabama & Mississippi	Change in mussel species composition	Failure of fish host to traverse a creek impounded by backup of the Tennessee River	Isom and Yokley 1968
Kentucky Lake, Kentucky	Loss of *Fusconaia ebena*	One of its host fishes, the rosefin shiner (*Notropis ardens*), could not tolerate the impoundment	Yokley 1972
Ft. Loudon Reservoir, Kentucky	Loss of 60 species	Oxygen sag	Isom 1971
A dam on the Ogeechee River, Georgia	No mussels below spillway	Very cold water	Fuller 1974
Kentucky Lake, Kentucky	Widespread mortality of mussels	Acid mine drainage	Yokley 1973
Tensas River, Louisiana	Disruption of mussel growth	Flooding	Coker 1915

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PART XII. HABITAT CREATION FOR MUSSELS

Introduction

201. This Part considers an alternative to relocation (Parts IX and X) and protecting existing areas (Part XI) in order to preserve or protect freshwater mussels. The purpose is to discuss creating habitat for these organisms where previously there was only low-quality or unsuitable habitat. These high-quality flowing areas can also provide appropriate sources of food and cover for other organisms such as aquatic insects, crustaceans, and fish. Habitat development can occur (a) in conjunction with construction, (b) immediately following completion, or (c) during operation of a water resource project.

202. In many rivers, mussels congregate in groups or beds which are usually on gravel bars or shoals. A typical bar is composed of a mixture of sand, silt, and various sizes of gravel; it provides a stable substrate that a mussel can anchor to firmly and yet still move about fairly easily. In addition to the freshwater mussels, other aquatic organisms including snails, worms, insects, and fish such as sculpins, darters, and minnows are common inhabitants of gravel bars or portions of a waterbody with gravel substrate.

A Gravel Bar Design for the Tombigbee River

203. In October 1980, representatives of the U. S. Army Engineer District, Mobile, requested that scientists at WES prepare a design for a gravel bar for mussels and other aquatic species in a bendway of the Tombigbee River. The site was to be located below Columbus Lake Dam, river mile 232.9, near Columbus, Mississippi (Figure 12-1). Columbus Lake is a part of the Tennessee-Tombigbee Waterway (TTW), a navigation route which connects the Tombigbee River in Mississippi and Alabama with the Tennessee River in Tennessee.

204. On the west side of Columbus Lake is minimum-flow relief structure which directs water into an isolated bendway directly below

Columbus Dam (Figure 12-2). This structure removes up to 200 cfs of surface water and carries it under the dam where it enters a riprapped flume. The lake water then flows down the flume and into the uppermost portion of the bendway, less than 1 mile in length, which was isolated by the placement of Columbus Dam. The lower end of this bendway connects with the Tombigbee River about 1/2 mile downriver of the lock structure. When the TTW is complete, navigation traffic will bypass the bendway and move directly to and from the lock. However, fishing and pleasure boats can move up and down the bendway to the point where the riprapped flume enters.

205. The only source of flowing water in the bendway is the minimum-flow release structure located in Columbus Dam. Since the lower end of the bendway connects with the Tombigbee River, water levels in the bendway respond to changes in the river. However, because the upper end of the bendway terminates at the lower face of the dam, there is no continuous flow of Tombigbee River water through this area. Although the minimum-flow release structure directs up to 200 cfs of water into the upper end, no measurable current is produced except in the upper 50 to 100 yds of the bendway. The depth and width of the channel in this area are such that 200 cfs of incoming flow has virtually no influence on water movement throughout most of the bendway.

206. The proposed habitat will serve two functions, (a) provide suitable substrate consisting of gravel and sand for mussels and other aquatic species and (b) constrict the channel in the bendway to increase current velocity. The first step in the construction of this habitat will be to fill the upper 900 ft of the old bendway to an elevation of 130 ft (Figures 12-3 and 12-4). The required fill material could be any stable mixture of sand or gravel which can easily be obtained and transported to the area. Four distinct gravel bars will be created by capping fill material with specific sizes and mixtures of gravel or sand (See Table 12-1 for specific information on each gravel bar). Each cap of gravel (gravel bar) will be approximately 150 ft long and 170 ft wide (the width of the channel). The uppermost elevation of each bar will be at 137 ft msl, 1 ft above minimum levels for this pool. However, a

channel will be cut directly through the top of each gravel bar to allow the passage of water. The constriction of the bendway caused by placement of fill material and the gravel caps will increase the velocity of water current across the top of each gravel bar. Over bars I, II, and III, the flow will be maintained at 1.5 ft/sec; over the last bar it will be 1.0 ft/sec. These velocities will exist in the channels across each gravel bar when the Tombigbee River stage is at or below 136.5 ft.

207. Between each gravel bar will be a single pool measuring approximately 100 ft in length and 100 ft in width. The bottom elevation in each pool will be at 130 ft msl, which will be at the top of the 900-ft length of fill material originally placed in the area. It is anticipated that sedimentation will occur in these pools during all conditions of flow in the Tombigbee River. In the unlikely event that the pools fill completely with sediment, a channel would always be maintained by flowing water.

208. When the river stage exceeds 137 ft msl, which will occur 60 percent of the time, the entire surface of each gravel bar will be covered with water (See Figure 12-5). The flowing water will no longer be constricted to the narrow channels on the top of each bar. When water flows out of the channels and over the gravel bar surface, the water velocity will decrease in the channels from either 1.5 or 1.0 ft/sec to essentially 0. When this happens, sedimentation will take place. Silt and clay particles will settle on the bars and in the channels cut through the top of each bar.

209. When the river stage drops to 136.5 ft msl or lower, the flow over bars I-III will increase to 1.5 ft/sec and over bar IV to 1.0 ft/sec. Based upon Vanoni (1975), a flow of at least 1.5 ft/sec is required to erode previously settled clay particles. The flow will be sufficient to remove silt or clay from the substrate but not disturb the gravel or sand-gravel mixtures in each channel. At gravel bar IV the flow will be 1.0 ft/sec so that some previously deposited silt or clay will probably not be eroded from the channel. However, as material deposits in the channel at bar IV, constriction will gradually take place and current velocities will increase. Ultimately, an equilibrium

between deposition and erosion will exist in this channel; water velocities will probably eventually range between 1.0 and 1.5 ft/sec.

210. The first gravel bar, to be constructed of the largest size materials (Table 12-1), should be suitable for large, thick-shelled molluscans that are typically found in the riffle areas composed of gravel and/or cobble substrate. The second bar is designed to be very similar to the first, except that particle sizes will be smaller and more uniform. The third gravel bar will be similar to the second; however, to add physical diversity, it will contain approximately 60 percent sand by weight. The fourth bar, to be composed mainly of sand, (80 percent) will produce reduced current velocities and resemble the preferred mussel habitat defined by Kaskie (1971). The pools between each bar will initially have a gravel or sand bottom. However, fine particulates from Columbus Lake or the Tombigbee River are expected to accumulate because of reduced to nonexistent water current.

211. Columbus Lake is at an embryonic state, and it is difficult to know to what extent this impoundment will affect the waters flowing through the minimum-flow release structure as it matures. Impoundments such as Columbus Lake usually retain and modify materials such as silt and inorganic and organic nutrients (Baxter 1977). However, physical and chemical studies on the water in the bendway in October 1981 indicated no particular conditions which could prove inimical to aquatic life. In addition, water quality below existing reservoirs on the Tombigbee River indicate that conditions will be suitable for mussels. One possible problem could be competition by large numbers of Corbicula which frequently invade so-called "altered" habitats (Fuller and Imlay 1976, Vidrine and Bereza 1976). Although not much is known concerning this problem, it is WES's opinion that a habitat with a diversity of substrate and flow (such as has been designed for the area below Columbus Dam) will help reduce the likelihood of invasion.

212. The gravel bar complex described above does not have certain features which are found in areas with natural flow characteristics. Most significant will be an absence of the periods of high and turbulent water which scours the channel in most streams; in their place will be

periods of high and slack water. The scouring period will actually occur at times of low flow when water is retained in the channels across the gravel bars. Keller and Melhorn (1978) and Keller (1978) described the spacing of pools and riffles in natural and channelized streams. If gravel bars are contemplated in areas experiencing the normal periods of high and low water, then the work of the above authors should be consulted. It is WES's opinion that suitable areas for mussels can be developed in conjunction with many water resource projects. Although certain criteria for water quality (see Part XI) must be met, WES feels that flow, depth, and substrate composition can be altered fairly easily and cheaply to create mussel habitat. In addition to sites below minimum-release structures, suitable areas probably exist in many parts of the country below lock and dam structures and impoundments and in streams which flow into larger waterways.

Mussels and Disposal Areas

213. Although detailed studies have yet to be done, representatives from the U. S. Army Engineer District, Nashville, have noted that freshwater mussels can reinvade dredged material sites. This was observed in larger rivers where gravel or sand and gravel was disposed of around islands. The dredged material was deposited where the substrate consisted primarily of hard-packed, well-scoured clay or other material. At some of these sites, mussels were found on the recently deposited material within 5 to 7 years.

Table 12-1

Physical Characteristics of Proposed Gravel Bar Habitat,
Tombigbee River, Mississippi

Parameter	Description			
	Bar I	Bar II	Bar III	Bar IV
Bar length, ft	150	150	150	150
Bar width, ft	175	175	175	175
Channel width, ft	60	60	75	115
Channel depth, ft	1.5-3.9	1.5-3.9	1.5-2.9	1.5-2.9
Substrate Description:				
Gravel, in. (%)	1-5 (80)	1-3 (60)	1-3 (40)	1-3 (20)
Sand (%)	(20)	(40)	(60)	(80)
Water velocity, ft/sec	1.5	1.5	1.5	1.0

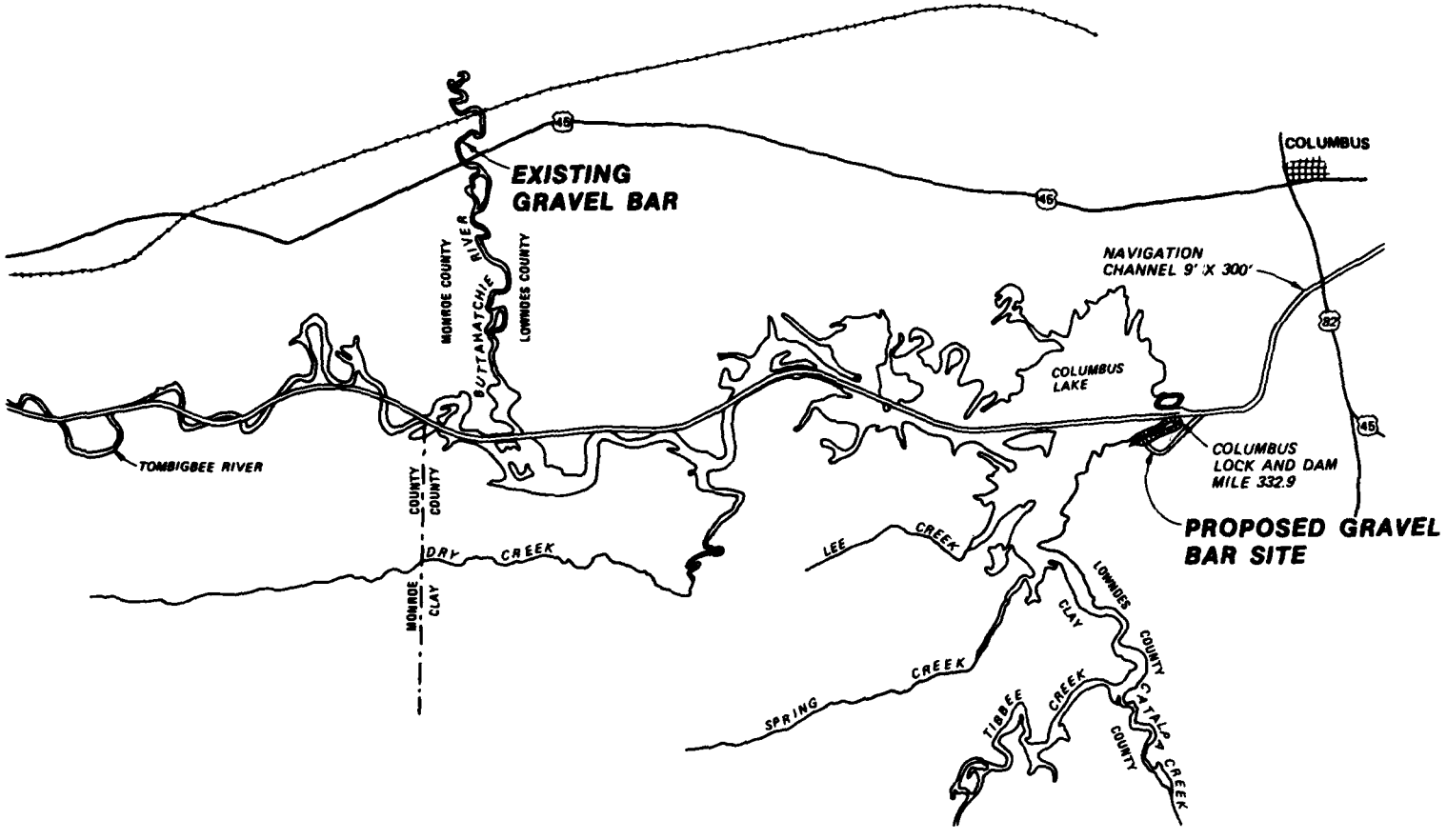

Figure 12-1. The bendway below Columbus Lake on the Tombigbee River, Lowndes County, Mississippi

Figure 12-2. The minimum-flow structure located in Columbus Dam on the Tombigbee River, Lowndes County, Mississippi (top). Water from the minimum-flow release structure moves under the dam down a riprapped channel and into a bendway of the Tombigbee River, Lowndes County, Mississippi (bottom)

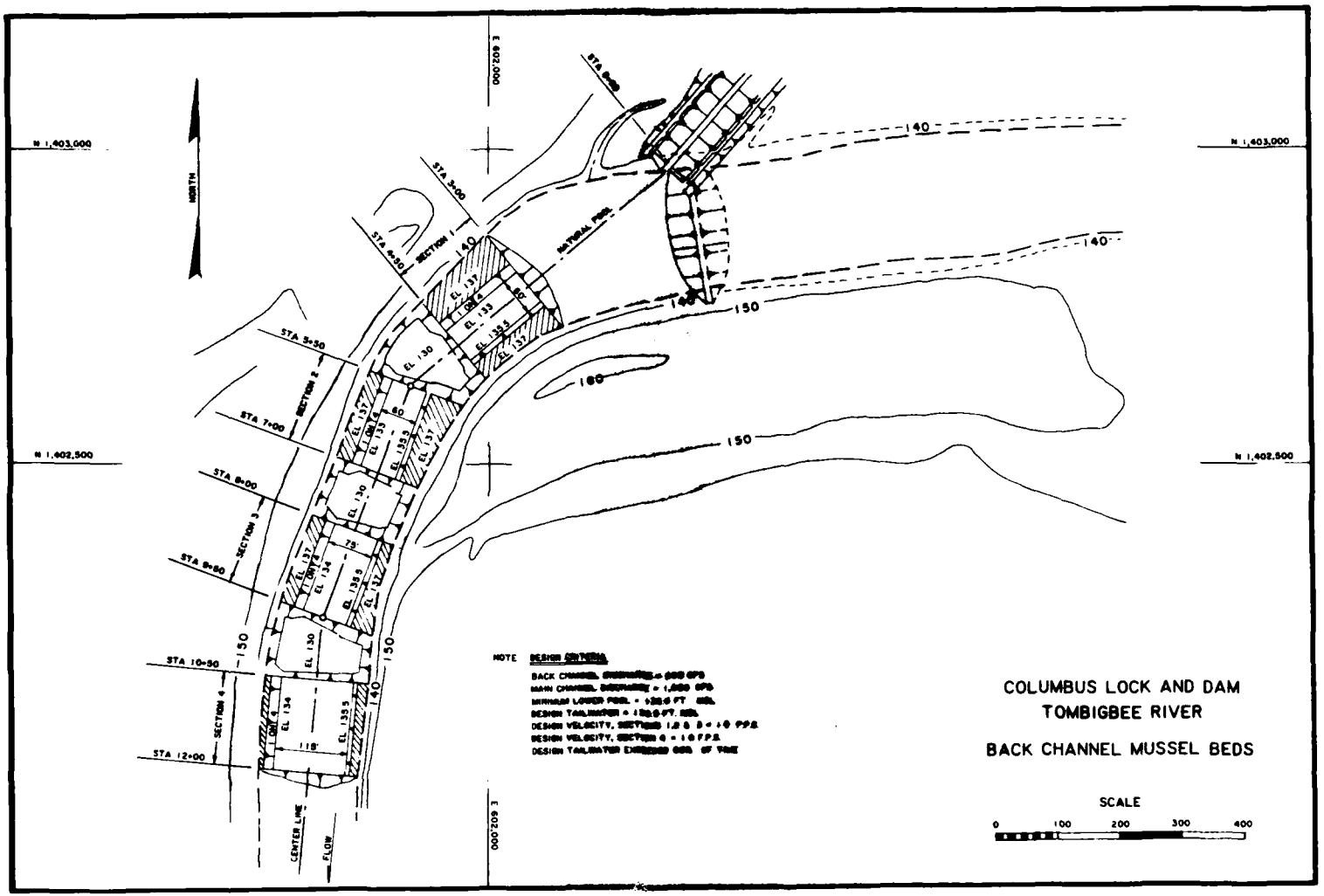

Figure 12-3. Design plans for the **gravel bar habitat** proposed for placement in the bendway of the **Tombigbee River**, Lowndes County, Mississippi

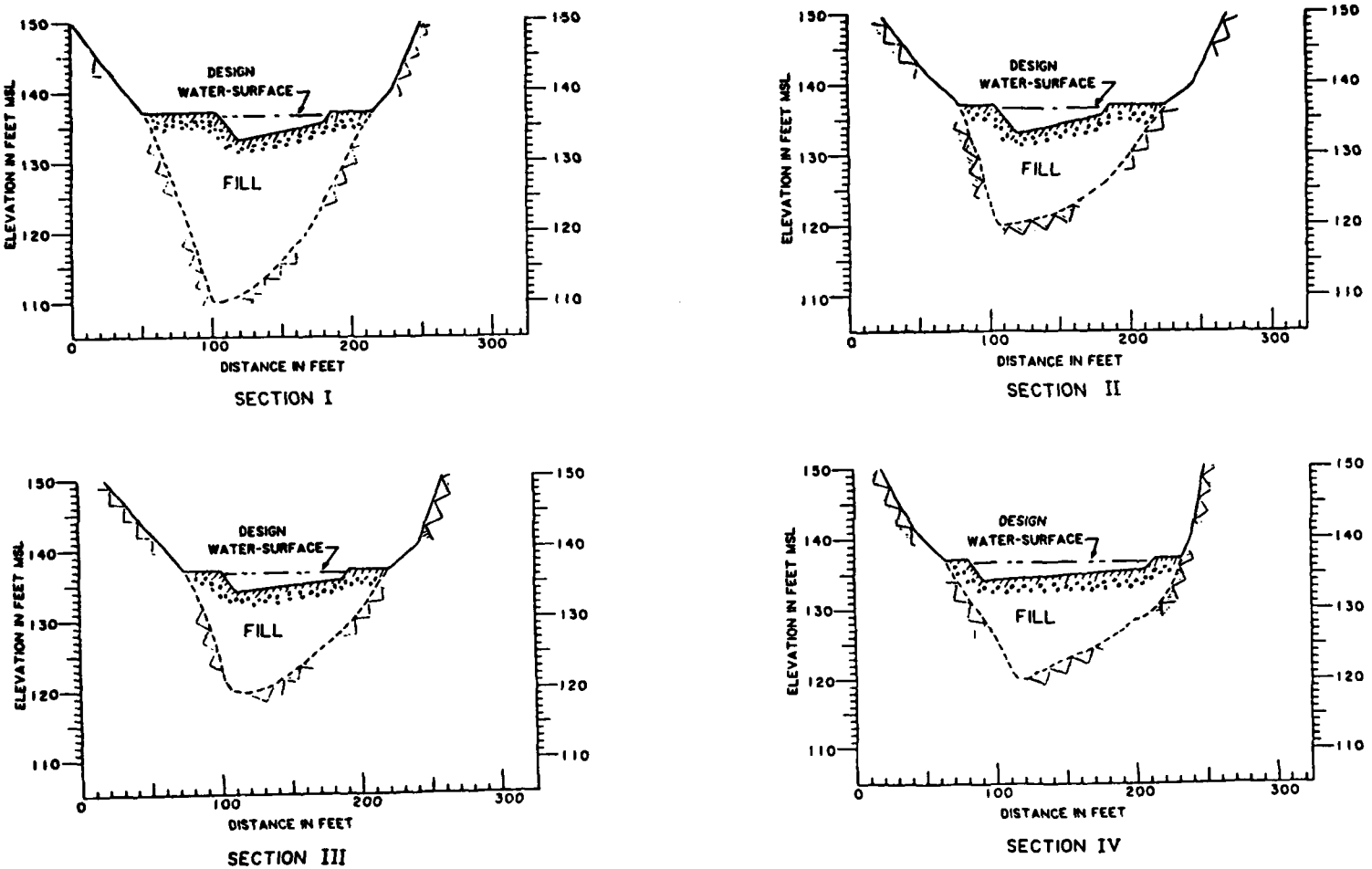

Figure 12-4. Transverse section of the gravel bars proposed for placement in the bendway of the Tombigbee River, below Columbus Dam, Lowndes County, Mississippi

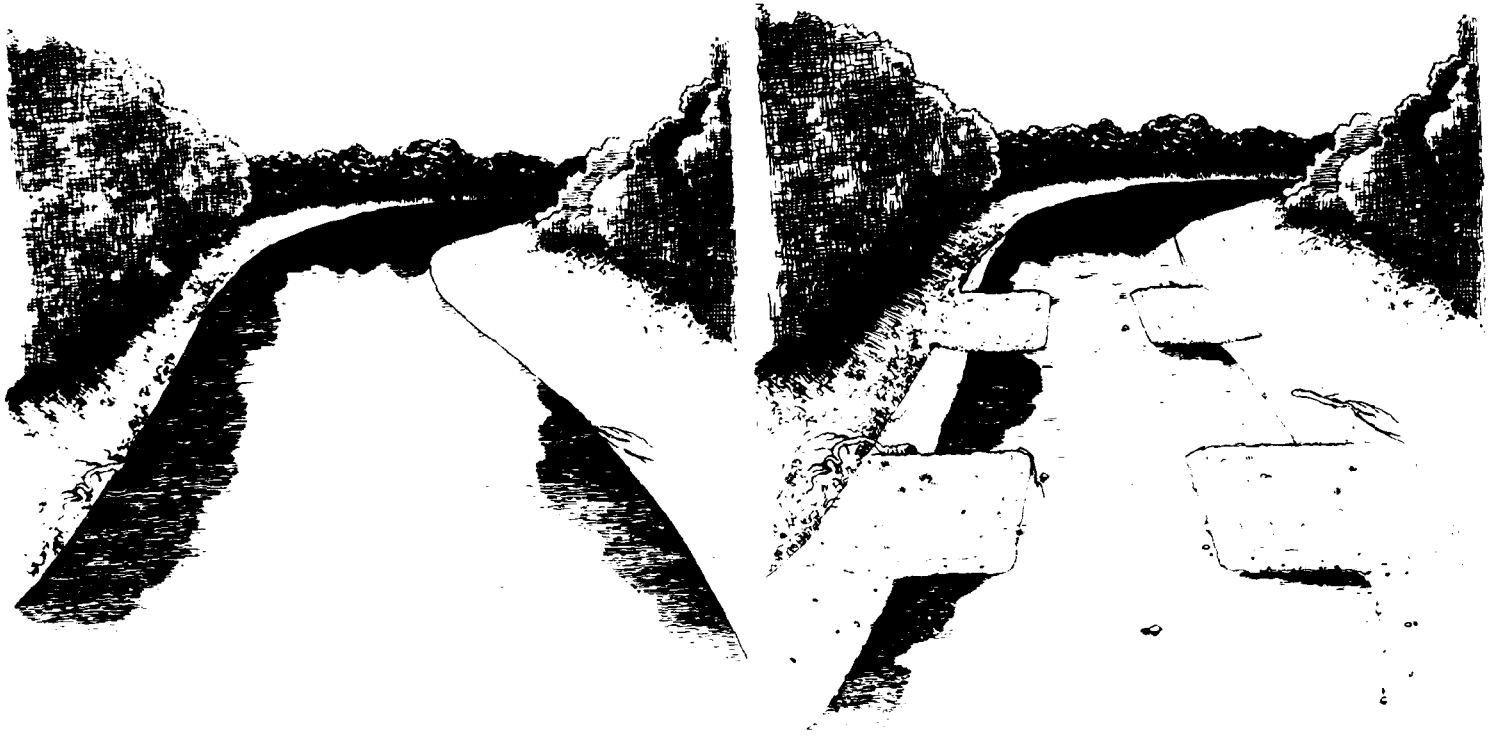

Figure 12-5. Artist's conception of gravel bars I and II at high-water (little or no flow) and normal-to-low-water (high flow across the bar) conditions

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PART XIII: TECHNICAL LITERATURE ON MUSSELS

Introduction

214. The following is a very brief summary of pertinent literature on mussels. The selected literature is by no means a complete list, especially regarding the distribution studies or reports of fauna from a particular drainage. For more information see "An Annotated Bibliography of Freshwater Mollusks of the United States," assembled by Dr. A. H. Clarke, ECOSEARCH, for WES and containing over 600 citations, some fairly recent and some of historical interest.*

215. The following citations have been divided into those pertaining to distribution (Table 13-1), general biology (Table 13-2), ecology (Table 13-3), artificial propagation (Table 13-4), sampling techniques (Table 13-5), impact studies (Table 13-6), age and growth (Table 13-7), endangered species (Table 13-8), and general information (Table 13-9). For a list of taxonomic keys for mussels in various parts of the United States, see Part VIII.

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* Available from Dr. Andrew Miller, WES.

Table 13-1

Distribution of Freshwater Mussels

Mussel Source	Reference
Cumberland River	Neel and Allen (1964), Wilson and Clark (1914)
Tradewater River (Ohio River tributary)	Clench and van der Schalie (1944)
Green River (Ohio River tributary)	Clench and van der Schalie (1944), Ortmann (1926), Williams (1969)
Salt River, Kentucky	Rosewater (1959)
Kentucky River	Danglade (1922), Ortmann (1913)
Kansas	Buchanan (1981), Murray and Leonard (1962), Scammon (1906)
Missouri	Utterback (1915-1916)
Meramec River	Buchanan (1980)
Virginia	Beetle (1973), Johnson (1970)
Wisconsin	Baker (1928), Mathiak (1979)
Illinois	Parmalee (1967), Starrett (1971)
Indiana	Baker (1922), Blatchley and Daniels (1903), Call (1900), Clark (1976), Danglade (1915), Daniels (1915), Goodrich and van der Schalie (1944), Meyer (1974), Stein (1881)
Michigan	Goodrich (1932), Heard (1961), Heard and Burch (1966), van der Schalie (1936, 1938a, 1941)
Ohio	La Rocque (1967)
Pacific Drainage	Clarke (1981b), Hannibal (1912), Ingram (1948), Taylor (1975)
Upper Tennessee River	Coker and Boepple (1912), Ortmann (1918), Stansbery (1973), Stansbery and Clench (1975)
Lower Tennessee River below Walden Gorge	Ortmann (1925), van der Schalie (1939a)
Tennessee River (Indian mounds near Muscle Shoals)	Morrison (1942)
Indian Creek and Bear Creek (tributaries of the Tennessee River in Alabama)	Isom (1968), Isom and Yokley (1968a)
Duck River (tributary of the lower Tennessee River)	Isom and Yokley (1968b), Ortmann (1924a), van der Schalie (1973)

(Continued)

Table 13-1 (Concluded)

Mussel Source	Reference
Mississippi River	Grantham (1969), Hartfield (1982)
Maumee River (Lake Erie)	Wilson and Clark (1912)
St. Joseph River (tributary of the Maumee)	Ortmann (1924b)
The Great Lakes	Clarke (1981b), Goodrich and van der Schalie (1932)
Lake Erie	Grier (1918), Stansbery (1961)
Cahaba and Tombigbee Rivers	van der Schalie (1938b, 1939a)
Coosa River, Alabama	Hurd (1974)
Ozarkian fauna	Call (1895)
Mississippian fauna	Baker (1928), Call (1900), Goodrich and van der Schalie (1944), Heard and Burch (1966), Murray and Leonard (1962), Parmalee (1967), Starrett (1971), Valentine and Stansbery (1971)
Canadian Interior Basin	Clarke (1973), Clarke (1981b)
Atlantic Drainage	Athearn and Clarke (1962), Clarke (1981b), Clarke and Berg (1959), Clarke and Rick (1963), Fuller (1971, 1972, 1974), Harman (1970), Johnson (1970, 1972), Shelley (1972),
Apalachicolan fauna	Athearn (1964), Clench and Turner (1956), Fuller and Bereza (1973), Johnson (1967, 1968)
Alabama River System	van der Schalie (1938a, 1939b), Hurd (1971), Isom and Yokley (1968a)
Texas	Strecker (1931)
Louisiana	Coker (1915), Frierson (1897, 1902, 1911), Shira (1913), Vanatta (1910), Vaughan (1892)
Arizona	Bequaert and Miller (1973), Stearns (188[illegible], Taylor (1966), Taylor (1975)
New Mexico	Cockerell (1902), Henderson (1933), Taylor (1975)
Florida	Athearn (1964), Clench and Turner (1956), Johnson (1970)
Georgia	Johnson (1970), Thomas and Scott (1965)
Lake Texoma, Oklahoma	Valentine and Stansbery (1971)
Tombigbee River	van der Schalie (1939b)
Ohio River	Williams (1969)
North and South Carolina	Johnson (1970)

Table 13-2

General Biology of Freshwater Mussels

Subject	Reference
Behavior	Heard (1964)
Gonadal activity	Heard (1969)
Anatomical systematics	Heard (1974)
Iron metabolism	Hobden (1970)
Parasite-induced pearl formation	Hopkins (1934)
Bioassay tests	Imlay (1971)
Tritogonia verrucosa	Jones (1931)
Parasites of mussels	Kelly (1902)
Visceral area	Landacre (1902)
Life history	Matteson (1948), Yokley (1972)
Natural history	Matteson (1955)
Glochidia	Merrick (1930), Olson (1969)
Names for unionids	Morrison (1969)
Breeding in Pennsylvania	Ortmann (1909)
Glochidia discharge	Ortmann (1910)
Anatomy	Ortmann (1923)
Life cycle of Anodonta grandis	Penn (1939)
Life history of Amblema plicata	Stein (1968)
Locomotion	Trueman (1968)
Popular biological information	van der Schalie (1938c)
Hermaphroditism	van der Schalie (1966)
Mantle flapping behavior	Welsh (1969)
Food and feeding	Allen (1914, 1921, 1923), Bovbjerg (1957), Churchill and Lewis (1923)

Table 13-3

Ecology

Subject	Reference
Ecology and functional morphology	Allen (1963)
Fauna of a lake changing to a marsh	Baker (1927)
Competition	Banarescu (1971)
Size correlated with distinctive habitat types	Brown et al. (1938)
Distribution in a California reservoir	Fask (1971)
Competition between Corbicula and Unionids	Fuller and Imlay (1976)
Mussels of Lake Winona, Indiana	Headlee (1906)
Juvenile stages	Isley (1911)
The effects of the fall line on distribution	Jenkinson (1975)
Changes in distribution	Matteson and Dexter (1966)
Relationship to trout	Murphy (1942)
Shape and station	Ortmann (1920)
Lake Springfield, Illinois	Parmalee (1955)
Stream conditions	Patrick (1949)
Dallas County, Texas	Reed and Oliver (1953)
Record for deep water	Reigle (1967)
Mussels in loamy sand	Riggs and Webb (1956)
Bottom sediments	Sickel (1981)
Ten years of observation on mussels	van Cleave (1940)

Table 13-4

Artificial Propagation

Subject	Reference
Growth of Glochida in nutrient solution	Ellis and Ellis (1926)
Anodonta woodiana	Guerrero (1978)
Human consumption	Havinga (1964)
Rearing	Hoosanoff and Davis (1963), Howard (1914a)
Quadrula sp.	Howard (1914b)
A successful technique for culturing mussels	Isom and Hudson (1982)
General Information	Jones (1950), Lefever and Curtis (1910)
Metamorphosis without parasitism	Lefever and Curtis (1911)
Recent advances in clam aquaculture	Porter (1972)
Problems with rearing	Turner and Johnson (1969)

Table 13-5

Sampling Techniques

Subject	Reference
Finding mussels in creeks (by the expert)	Athearn (1969)
Mapping mussel communities in streams	Brice and Lewis (1979)
Distribution as determined with SCUBA	Cvancara (1972)
Comparison of Ponar and Crowfoot dredges	Kraemer and Gordon (1981)
White River, Indiana	Krumholz et al. (1970)
Asiatic clams	Mattice and Bosworth (1979)
Tennessee River	Scruggs (1960)
Sipsey River, Alabama	Smith (1911)
Collecting shells	van der Schalie (1974)

Table 13-6

Impact Studies

Subject	Reference
Channelization	Arner et al. (1979)
Extinction caused by pollution, exotic species, etc.	Athearn (1967)
Sewage and pollution	Baker (1920)
Need to protect shellbeds	Barret (1912)
Reservoir construction	Bates (1962)
Mussels as biological indicators	Bedford et al. (1968)
Comparison of pre- and post-impoundment of mussel fauna	Blankenship and Crockett (1972)
Recovery of the Clench River following floods and caustic waste spill	Crossman et al. (1973)
Effects of silt	Ellis (1936)
Radionuclide accumulation	Gardener and Skulberg (1965)
Thermal discharge	Graney et al. (1980)
Reservoirs	Harman (1974)
Pollution	Heard (1968)
Extinction	Imlay (1969)
Potassium	Imlay (1973)
Indicator organisms	Ingram (1957)
Fort Loudoun Reservoir, Tennessee	Isom (1971a)
TVA conservation program	Jenkinson (1981)
Acid streams	Jewell (1922)
Green River Reservoir	Kessler and Miller (1978)
Toxicity evaluation	La Rocque et al. (1970)
Pollution	Mackie and Qadri (1973)
Pesticides	Mane et al. (1979)
Silt	Moore (1937)
Polluted irrigation streams	Neel (1953)
Reservoir construction	Neel and Allen (1964)
Strontium-90	Nelson (1962, 1964)
Pollution	Shimek (1935)
Indicators of a recovery zone	Simmons and Reed (1973)
Uptake of mercury	Smith et al. (1975)
Amblema plicata as a pesticide monitor	Stein (1971)
Highway construction	Stein (1972)
Impacts of man's activities	Strayer (1980)
Pesticides	Varanka (1978)
Pollution	Wiebe (1928)
Stream pollution	Wurtz (1955)
Gravel dredging	Yokley (1977)

Table 13-7

Age and Growth

Subject	Reference
Megalonaias gigantea	Chamberlain (1933)
Anodonta sp.	Crowley (1957)
Rate in pond unionids	Frierson (1917)
General	Haskin (1954)
Growth and migration	Isley (1914)
Growth record	Isley (1931)
Multiple regression	Isom (1971b)
Growth of *Amblema plicata*	Little and Gentner (1970)
Growth and reproduction	Negus (1966)
Metal content of variously aged shells	Saville and Sterrett (1975)
Growth in Lake Erie	Stansbery (1967, 1971b)
Growth of muckets	St. Johns (1975)

Table 13-8

Endangered Species

Subject	Reference
L. orbiculata	Buchanan (1980)
L. orbiculata and *Dysnomia curtisi*	Buchanan (1981)
North American species	Clarke (1970)
Northwestern species	Clarke (1977)
Lampsilis higginsi	Havlik (1981)
Competition	Imlay (1977)
Dysnomia sulcata	Isom et al. (1979)
Lampsilis orbiculata, *L. higginsi*, *Proptera capax*	Johnson (1980)
Proptera capax	Murray (1962)
General information	Parker and Dixon (1980), Stansbery (1971a), (1976a), Stein and Imlay (1977)

Table 13-9

General Information

Subject	Reference
Transplant	Ahlstedt (1980)
Commercial use	Anonymous (1902), Clark (1971) Ellis (1931)
Formation of a glochidial cyst	Arey (1932a)
Glochidial nutrition	Arey (1932b)
Effects of oxygen deprivation	Badman (1974)
Archaeology	Baker (1931, 1941)
Competition and distribution	Banarescu (1971)
Salt marsh development and mollusks	Cammen (1976)
Glochidia in surface plankton tows	Clark and Stein (1921)
Unionid relocation	Clarke (1967)
Commercial mussel industries	Coker (1918)
Raising mussels in enclosures	Corwin (1920)
Commercial use of M. margaritifera in Great Britain	Cranbrook (1976)
Maintaining A. plicata in a natural system	Fikes (1972)
Multivariate statistics and distribution	Green (1972)
Definition of terms used by 18th and 19th century malacologists	Marshall (1930)
Nomenclature	Ortmann and Walker (1922)
Sex reversal	Pip (1973)
Aerial dispersal	Rees (1966)
Archaeology	Roscoe (1967), Baker (1936)
Tagging mussels	Rosenthal (1969)
Effects of lampricides on invertebrates	Rye and King (1976)
Biomass of mollusks consumed by muskrats	Shiryaev (1976)
Predation by birds	Snyder and Synder (1969)
Host-glochidial relationships	Stern and Felder (1978)
Variation based on habitat types	Stratton (1960)
Natural hosts	Surber (1912)
Glochidia	Surber (1915), Clarke (1981a)
Taxonomic problems	van der Schalie (1952)
Zoogeography	van der Schalie and van der Schalie (1950)
Evolution	Walker (1917)

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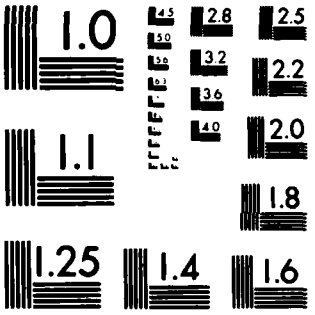

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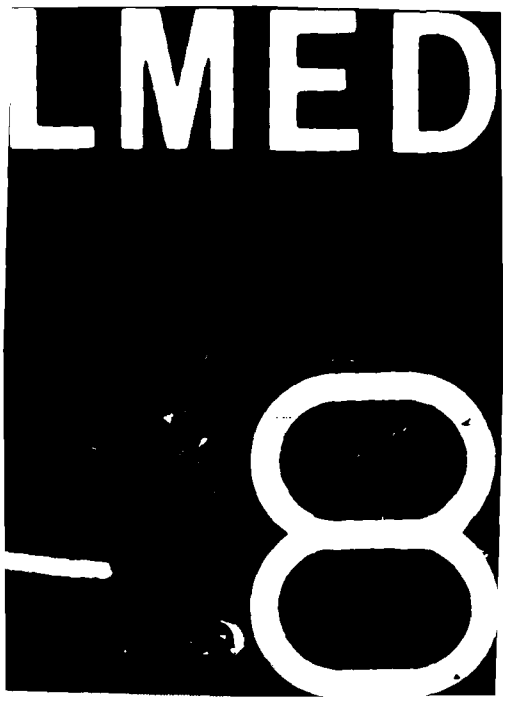
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